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AN ARCTIC AURORA

SCIENCE FOR ALL.

EDITED BY

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SCIENCE FOR ALL.

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THE NORTHERN LIGHTS.

BY GEORGE WILLIAM VON TUNZELMANN.

SOME of us have seen, even in these latitudes on certain rare occasions, beautiful arches of light stretching across the heavens, rapidly changing in form and colour, with now and again bright rays flashing out perpendicularly from them. (FRONTISPIECE and Figs. 1, 2, 6, 7).

To observe these phenomena, however, in all their beauty, we must pay a visit to higher latitudes,* where they are seen much more frequently, and in far greater splendour.

These appearances are most generally known as the Northern Lights, the Merry Dancers, or the Aurora Borealis, owing to the fact that the high northern latitudes have been much more visited than the southern. The same phenomena, however, are to be seen as we go southwards, and so they are sometimes spoken of under the name of the Aurora Australis. We have chosen the most popular name for our title, though perhaps the most appropriate one that has been applied to them is that of Aurora Polaris, As few of those who read this will ever have the opportunity of actually visiting either the northern or the southern polar regions, let us imagine ourselves for a brief season to be upon the deck of a vessel far away in the north—let us say in the autumn, just before the approach of the long Arctic night. As we glance round, all looks cold and bleak. There is light enough for us to see on every hand the fantastic forms of the icebergs looming up in the darkness. We hear the grinding of the bergs together, and cannot suppress an uncomfortable feeling as the contingency presents itself to our mind of the ship getting aground between two of those huge floating ice islands.

As we look, the scene changes as completely as though a magician's wand had transferred us to one of the jewelled palaces of the *Arabian Nights*. We

* They may be observed in greater perfection in moderately high latitudes than in the extreme north. For instance, few auroral displays were witnessed at Floe Berg Beach, in Smith's Sound (lat. 82°, 27′ N.) during 1875-6, when the *Alert* wintered there. The Arctic Auroræ are also of a pale straw-colour, reflecting more light than what one sees in the North Sea, where the usual phenomena witnessed consist of a brilliant arch extending from one horizon to another, with red and yellow flashes. "I remember, on returning from Beechey Island in the month of September, admiring the North Sea Aurora as a more showy phenomena than the modest but beautiful Northern Lights that we had been accustomed to see during our two winters in Wellington Channel." (*Captain May, R.N.*)

see arches of light stretching across the heavens from east to west—sometimes remaining stationary, and sometimes moving slowly towards the south. Rays of light shoot out perpendicularly from the arches, and if the arches are below the horizon we only see these rays, which, though really parallel, often appear as an effect of perspective to meet in a point in the zenith. These rays very seldom remain stationary, but shoot upwards towards the zenith, at the same time moving eastwards, often with a tremulous, snake-like motion from end to end, till sometimes they cover the whole sky.

If now we turn our eyes from this magnificent sight to look down again upon the surrounding mass of bergs which just now looked so weird and gloomy, we can scarcely believe that they are the same, for now they throw back to us in a thousand colours the light that flashes on them from above, and the peaks and pinnacles of the bergs appear to be set with jewels of the most varied hues and the most dazzling brightness.

The rays appear in the most varied forms and patterns, in one of the most beautiful of which, though seldom seen, the rays seem to hang from the sky in folds like a mantle.

It is at present rather doubtful whether the auroral displays are or are not accompanied by any sound. Many observers have asserted that during an aurora they have heard crackling and hissing sounds; and some experiments made by M. Planté, to which we shall presently recur, as they throw great light on the theory of the aurora, decidedly support this view. On the other hand, some of the most eminent polar explorers* have listened in vain for these sounds, and have given it as their opinion that what was heard was merely the breaking up of the ice, and the grinding of the icebergs.

Having now in our mind the appearance of these northern lights, we will repeat a well-known laboratory experiment. We take a glass cylinder, covered at the ends with brass caps, one of which is fitted with a stop-cock, which we can screw to the plate of an air-pump. To the brass caps we now attach the terminals of a powerful induction-coil, but as yet we perceive no result. We now begin to exhaust the air from the cylinder, and as the exhaustion goes on we soon see a soft, tremulous light beginning to play about the ends of the cylinder; and this, when the air is sufficiently rarefied, gradually extends right through the cylinder. As we continue the exhaustion, these phenomena will be reversed, the light gradually dying away as the exhaustion increases. We shall at once perceive how very much this resembles an aurora on a small scale, and so we have electricity suggested to us as the agent which produces the aurora.

Now, before we pursue further the path of inquiry which this analogy opens up to us, I should like to point out that when we speak of magnetism or of electricity we are really speaking of the same agent. Of the inner nature of electricity we are at present in ignorance, and we do not know exactly what change a piece of iron or of steel undergoes when it is magnetised by being brought under the influence of an electric current; but I may mention that a coil of wire, with a current passing through it, behaves in every way just like a magnet. (Vol. I., p, 47).

Now we all know the great discovery made by Sir Isaac Newton, that every portion of matter attracts every other portion with a force which depends upon the masses of the two portions of matter, and upon the distance between them. To fix the ideas, suppose one of the portions of matter to be the earth, and the other a body, such as a balloon, moving near its surface. Then if the balloon rises, the attraction of the earth upon it diminishes; while if the balloon falls, the attraction increases. Thus the force which the earth exerts upon the balloon varies in intensity in a way which depends merely on the distance of the balloon from the surface of the earth. We may say, then, that the balloon is moving in a field of force of varying intensity. The action of this force at every point of the field is to pull the balloon perpendicularly downwards to the earth, and so if through any point of the field—that is, any point within the sphere of the earth's attraction—we draw a line perpendicular to the earth, we shall have what is called the line of force through the point.

Now, if we take a magnet of any form, it will be in the same way surrounded by a field of force, and the shape of the lines of force, and the manner in which the intensity varies from point to point will depend on the form of the magnet.

In this case the line of force at any point is the direction in which a magnetised particle would tend to move if it were placed at that point. The lines of force in the neighbourhood of a single pole, or of two poles respectively, may easily be shown by placing a card above one of the poles of a bar magnet, or over the two poles of a horseshoe magnet,

* Among others, Sir George Nares and his companions, who also considered that the faint auroral displays seen from their winter quarters were "in no way connected with electrical or magnetic disturbances."

and sprinkling iron filings upon it, when they will range themselves along the lines of force, which in the first case will radiate from the single pole, and in the second case will arrange themselves in a series of curves, which are delineated in Fig. 4, p. 183, Vol. I.

Now the earth is a great magnet, and the direction of the line of force through any point on its surface is easily found in the following manner.

We first take a needle, and suspend it in such a manner that when magnetised it will turn freely in a horizontal plane. If now we take a line on the earth's surface through this point in the direction in which the needle comes to rest, we get what is called the magnetic meridian at that point; and the angle between this and the geographical meridian is called the *declination*.

We next balance a steel needle very accurately upon a horizontal pivot, and place it so that it can turn freely in the vertical plane passing through the magnetic meridian. We shall find in these latitudes, that when magnetised, the north-seeking end of the needle will point downwards at a considerable angle to the horizontal, which is called the angle of *dip*, the needle being called the dipping-needle.

The direction of the needle now gives us the direction of a line of force, and we find that the lines of force start from near the poles and rise to a great height above the surface of the earth near the equator. Now, the rays which are seen in the aurora are always parallel to the dipping-needle—*i.e.*, to the magnetic lines of force, and this is another indication that electricity is in some way or another the agent in auroral displays.

The rising upwards of the lines of force as they approach the equator gives us one reason that auroræ are seen more often, and to greater advantage, as we approach the poles, for the lines of force rise to such a height that even if the display took place so high up it would become more and more difficult, and at last impossible for us to see them. Most probably, however, the displays would not take place at these great heights, owing to the extreme rarefaction of the atmosphere, just as we found in the case of the exhausted cylinder, that when the exhaustion was carried beyond a certain point, the discharge took place with continually decreasing intensity, and finally ceased altogether.

Probably some of my readers have noticed that when the current from a powerful induction-coil was being sent through the so-called vacuum tubes, which are really tubes filled with rarefied gas, a tendency to stratification, or the formation of striæ, was distinctly observable. With special appliances, only in the hands of a very few scientific workers—such as Mr. Warren de la Rue's chloride of silver battery, or Mr. Spottiswoode's large induction-coil, furnished with a contact-breaker which works with great regularity, and, if desired, at a very high speed—these striæ can be obtained with a perfect distinctness and uniformity, looking like a row of discs placed at regular intervals one in front of the other, and can be made to remain stationary or to move slowly or rapidly along the tube, by altering the electrical resistance of the circuit or the speed of the contact-breaker. These striæ are exactly analogous to the arches in the aurora, for the arches, as they appear to us, are in reality circles concentric with the magnetic pole.

Again, the intensity of the magnetic force at any place, the declination, and the angle of dip, are subject to variations, some of which are periodic—diurnal, annual, and some of longer periods; and others are sudden and irregular, and brought about in a manner about which we know very little, though comparatively recent researches have shown us that these sudden irregular disturbances, or magnetic storms as they are called, are very closely connected with the solar storms which show themselves to us as sun-spots, and with the nature of which we are gradually becoming acquainted through the wonderful revelations of the spectroscope. We should therefore expect the auroral displays, if really magnetic phenomena, to show some connection with these magnetic storms; and as a matter of fact we find that auroræ are only to be seen during the prevalence of these magnetic storms.

The magnetic storms are not by any means only to be detected by means of special instruments for observing changes in intensity, declination, and dip, or as we usually say, changes in the magnetic elements; for when these storms are at all considerable, strong currents are produced in the telegraph-lines, and in some instances the telegraph operators have been obliged to cease working the line during the prevalence of the magnetic storm.

Auroral displays usually take place at a great height—sometimes as high as 300 miles—while their average height is over 100 miles. At such heights the air must be extremely rarefied, and we should be disposed to expect that the electric discharge could not take place through it.

Let us now return to the laboratory, and see

whether we can make any experiment which will throw light upon this difficulty. If we send the electric discharge through one of the so-called vacuum-tubes—choosing one which consists, throughout part of its length, of tube which is much narrower than the main portion—we find that when the discharge is passing the pressure is greater in the narrow part of the tube, showing that in some way gas is being carried along by means of the current, and Professor A. S. Herschel suggests that in some similar way air may be electrically carried up to these great heights.

When the light of the aurora is examined by means of the spectroscope, it does not simply give, as might be expected, the spectrum of rarefied air; but the chief feature of the spectrum is a single greenish-yellow line—a spectrum which is totally different from that of oxygen and nitrogen, the gases of the atmosphere. A red line is also frequently seen in the spectrum of the aurora, and its brightness seems to vary in an inverse ratio with that of the green line. Besides these two chief lines, some fainter ones are generally discernible, which appear to coincide with those which are seen in the spectrum of rarefied atmospheric air.

This variability in the spectrum shows us that the light must either come from different sources, or be produced under varying conditions. Now, it is a tolerably well established fact that many substances give a peculiar spectrum when undergoing decomposition—that is, when the elements of which they are composed are passing out of an old combination into a new one. This suggests a very probable explanation of the peculiar spectrum of the aurora; for if, as is most likely, the electric discharge takes place between particles of ice or of water, there will be a decomposition going on at the surface of these particles, just as in the laboratory we are able to effect the decomposition of water into its constituent gases by passing through it a current from a galvanic battery, or a magneto-electric machine. Some experiments made by M. Planté,* throw so much light upon the phenomena of the aurora, that they cannot fail to interest the reader. In these experiments the author studies the behaviour of the electric discharge from a powerful battery in the presence of aqueous masses, so that the conditions are assimilated as nearly as possible to those which occur on the large scale in these polar lights.

A glass vessel is partly filled with salt water, and the inner surface of the vessel above the water is moistened with the solution. The wire from the negative pole of the battery—or as it is usually called, the negative *electrode*—is now immersed beneath the surface of the liquid, and then the positive electrode is put in contact with the moist sides of the vessel. If we begin by placing the positive electrode in contact with the side of the vessel at some little distance from the surface of the liquid, and gradually lower it towards the liquid, a series of phenomena are seen, presenting a most complete analogy to the polar lights.

First we have a wreath of light completely surrounding the positive electrode, as is shown in Fig. 3. As we lower the point of contact between the positive electrode and the side of the vessel, this wreath gradually changes into an arc of light, with bright rays darting out from it, as in Fig. 4, and then this again changes into a sinuous line, which continually folds and re-folds upon itself with a wriggling snake-like motion, which exactly represents on a small scale the serpent-like undulations frequently seen in the auroral light. Fig. 5 will give an idea of the appearance of this sinuous

* "Comptes Rendus," vol. lxxxiii.

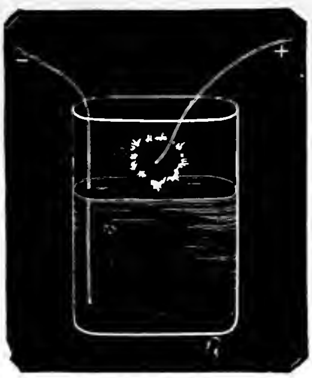

Fig. 3.—Showing the Wreath of Light completely surrounding the Positive Pole.

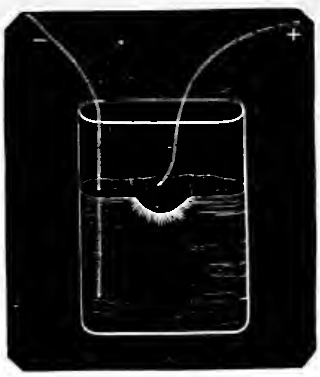

Fig. 4.—Showing the Wreath changed into an Arc of Light, with bright rays darting from it.

Fig. 5.—Showing the Wreath changed into a sinuous Line with bright rays shooting from it.

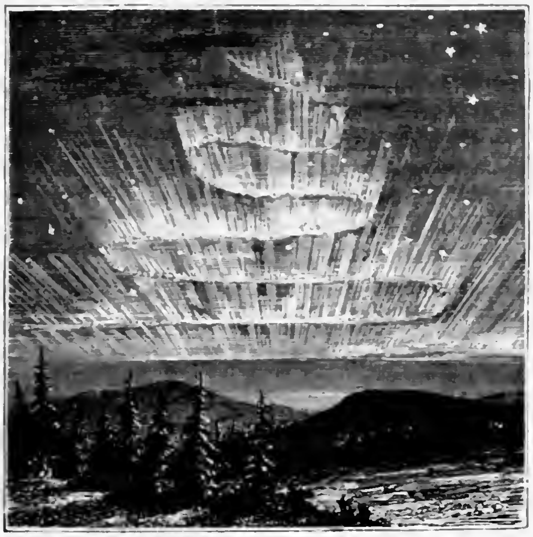

Fig. 6.—Aurora Borealis observed in Alaska, Dec. 27, 1865.

Fig. 7.—Aurora Borealis observed at Brevillepont, Sept 26, 1731.

line, with the bright rays shooting from it into the liquid.

The presence of salt in the water renders it a better conductor of electricity, but at the same time it causes a great predominance of yellow light in these experiments; we can, however, perceive purple and violet tints, similar to those seen in the aurora, at the parts where the condensed vapour is least charged with the salt. The rays which are seen darting out from the luminous arc are due to the penetration of the electric discharge into the liquid, and are an exact reproduction upon a miniature scale of the bright rays which in the aurora seem to be continually darting out from the arches.

In these experiments we notice that we do not always get a complete circle of light surrounding the positive electrode, while in the aurora the arcs are always such portions, as can be seen by the observer, of complete circles; this, however, is merely caused by the liquid not completely surrounding the electrode, and if we immerse it further into the liquid we get complete circles or luminous waves quite analogous to those of the aurora.

A crackling sound is heard during the experiments, due to the vaporisation produced by the electric sparks penetrating into the liquid, and this corresponds to the sound which, according to the statements of many observers, is produced during an auroral display. In considering the weight to be given to the negative evidence of several eminent Arctic explorers who have never heard these sounds, we must bear in mind that the polar lights are usually at a great height above the surface of the earth, and it would be only when they were exceptionally near to the earth that any sound, if produced, could be audible.

The liquid is thrown into a state of violent agitation by the electric discharge, and if the experiment be made with a small quantity of liquid, a fluctuation in the light is produced corresponding to that which characterises the polar lights.

We pointed out that the polar lights were always accompanied by great magnetic disturbances, and so it immediately occurs to us to try what will be the effect of suspending a magnetised needle in the neighbourhood of the electric circuit during the experiments; and we are not disappointed in our expectation that the analogy will hold good here also, for the deflection of the needle increases or decreases according as the luminous arc becomes more or less developed in the liquid.

There is still another phenomenon connected with the polar lights, for which we can find an analogy in these experiments—namely, the abundant falls of rain or snow which have always been noticed during the prevalence of an aurora, for in making the experiments it is found that the deeper we immerse the positive electrode in the liquid, the more abundantly is aqueous vapour liberated.

It is interesting to notice that these phenomena are only exhibited at the positive electrode of the battery, and nothing similar is seen at the negative electrode. M. Planté believes, from these and other

experiments, that in the aurora the imperfect vacuum of the upper regions of the atmosphere, forming a vast conducting envelope, plays the part of the negative electrode in these experiments, and that the light is caused by positive electricity flowing off from the earth, through the icy mists or clouds which float above the poles, towards the planetary spaces.

It may seem to some almost inconceivable that electricity can be thus flowing off towards other planets, and that therefore there must be some kind of electric communication between planet and planet. Yet the close relation between the terrestrial magnetic storms and the prevalence of sun-spots, which is now a well-established fact, shows us that some such communication must exist; and other researches tend towards the same result.

To explain the transmission of light on the now universally received undulatory theory, we have to assume the existence throughout known space of a medium capable of transmitting light-vibrations.

Again, many electro-magnetic phenomena may be explained in by far the most natural way on the assumption that when different bodies are acting electrically upon one another, there is an actual transmission from one body to another of mechanical action by means of a medium occupying the space between them. Now, it would be a most unphilosophical proceeding to fill space with a new medium whenever any new phenomena are to be explained; but if, on the other hand, the study of two different sets of phenomena has independently suggested the idea of a medium, and if the properties which must be ascribed to the medium in order to explain one set of phenomena are found to be identical with the properties which must be ascribed to it in order to explain the other set, then the evidence for the existence of the medium is considerably strengthened.

Now, in the case in question we have the means of determining, independently from the two sets of phenomena, the rate of transmission of a disturbance, which can be directly observed in the case of light, and which can also be calculated from electro-magnetic experiments.

We are, unfortunately, not able to make either determination with sufficient accuracy to enable us to state absolutely that the two give us the same result, but if we take the mean of several of the most trustworthy determinations of the velocity of light, and the mean of the most accurate of the rate of transmission of an electro-magnetic disturbance, we find that the difference between the two results is less than the difference between some of the different determinations of the velocity of light or of the velocity of transmission of an electro-magnetic disturbance.

We thus obtain a strong confirmation of our supposition that both optical and electro-magnetic disturbances are transmitted by the same medium, and many other experiments lead us to the same conclusion suggested by this result—viz., that light is an electro-magnetic phenomenon. But we cannot now discuss this subject, as our object is not now to prove that light is an electro-magnetic phenomenon, but simply to point out what strong evidence there is to show that electrical action is transmitted at any rate between the different members of our solar system, and probably also from system to system.

Neither is this the place for us to speculate as to how far electric influence may extend throughout the universe, or whether science may one day tell us of some close connection existing between electrical action and that mighty discovery of the immortal Newton of the mutual action between all the parts of the physical universe which is known as "attraction of gravity," and which unites all its mighty systems into one great whole.

We have now been led step by step from the comparison of the phenomena of the polar lights with simple laboratory experiments to the consideration and explanation of their electrical origin, and at this point we must leave the reader; but before doing so we would merely remark in conclusion that great attention is now being given to the study of terrestrial magnetism, and phenomena connected with it, so that a few years will probably add very largely to our knowledge of the aurora.

THE MATHEMATICS OF PLANTS.

By George Dickie, M.A., M.D., F.L.S.,
Emeritus Professor of Botany in the University of Aberdeen.

THE great variety in the external aspect or habit of plants has relation to several conditions, such as the character of the stem as regards height, branching, &c. ; the size, form, colour, and covering of leaves, and their arrangement on the stem : in the latter respect there is generally clear evidence of definite order or law. The common observer may find a little difficulty at first in examining the subject, but some knowledge of it will add materially to the pleasure derived from the cultivation and examination of plants. We shall find that there is order in what looks at first sight most irregular, and that even the leaves of a plant are not attached to the stem without obeying certain fixed, though simple, mathematical laws. It is necessary at the outset to explain a few technical terms used by botanists. The part of the stem or axis to which a leaf is attached, or from which it springs, is called a *node;* the space or part of the axis between one node and the other, above or below, is called an

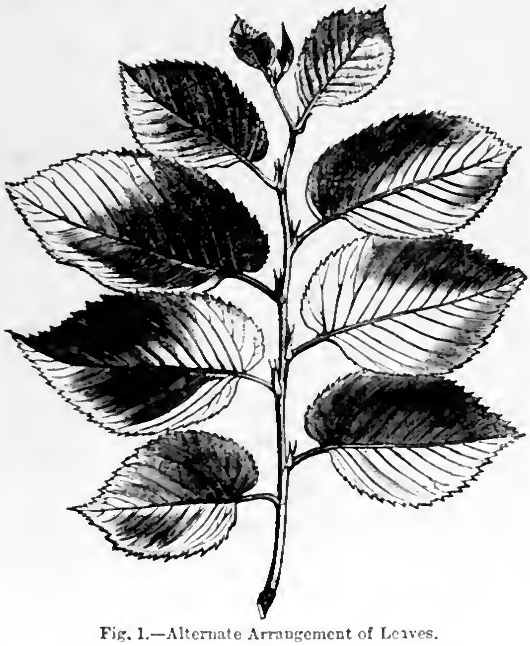

Fig. 1.—Alternate Arrangement of Leaves.

internode, and these spaces are longer or shorter in different plants. The relative positions of leaves on the axis, or the way in which they are distributed on the stem, is technically called phyllotaxis from two Greek words which signify *leaf*, and *order* or *arrangement*. Numerous treatises have been written on this subject by different observers, and it is considered to have relation to certain mathematical principles. A very common arrangement is that which is called *alternate* (Fig. 1), in which the leaves stand singly on the nodes. Some common plants are examples, as the poplar, the oak, the apple, &c. ; in other cases, a node appears to support two leaves —one on one side, another on the other side of the axis : the term *opposite* is applied to such cases (Fig. 2). In some cases a superficial examination

Fig. 2.—Opposite Arrangement of Leaves.

might lead to an erroneous conclusion, the two leaves being nearly but not strictly in opposition ; the term sub-opposite would be the correct expression in such, there being in reality a *short internode* between the two. Two of our native orchids, such as the twayblade (*Listera*), not uncommon in shady meadows and woods, may be mentioned as examples; and in a series of specimens a few may occur in which the leaves obviously come under the first or alternate arrangement, the internode being longer than usual. It is, however, worthy of notice that usually the pairs of opposite leaves alternate with each other—that is to say, if we place the stem before us, and observe a pair of leaves one on the right, the other on the left, the next pair will stand one in front and the other behind ; the successive pairs of leaves are then described as *decussate* (Fig. 3), but even this may not be strictly true, and several pairs of leaves may intervene between

those which are properly at right angles to each other.

Take, again, the common bed-straw (*Galium*), or madder, and we find the leaves arranged after what is known as the *verticillate*, or whorled manner (Fig. 4). Here we find that more than two leaves appear to come from the same transverse zone, or node. In these cases also we find alternation of leaves in the successive whorls—that is, each leaf usually stands opposite the spaces between the leaves of the next whorl.

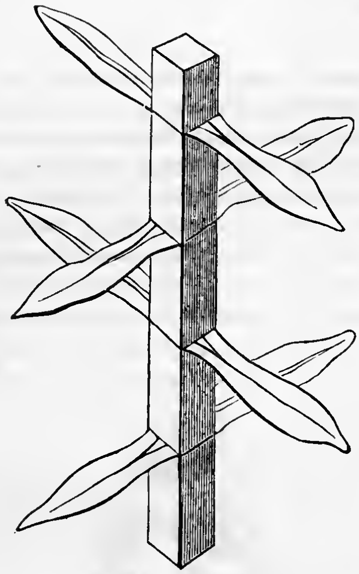

Fig. 3.—Decussate Arrangement of Leaves.

Fig. 4.—Verticillate Arrangement of Leaves.

It has been already stated that the length of the internodes materially affects the habit or external aspect of plants, and there may be such difference of their length on the same axis and at different periods of its growth. In some of our common native species of buttercup, the leaves on the lower part of the stem appear to be in close tufts; those further up are more widely separated, the internodes being longer.

If in the case of alternate leaves—like those of the elm or lime tree—we suppose a line drawn round the stem, and, touching the point of attachment of each leaf, it will be seen to be a spiral line; or fasten one end of a thread to the stalk of a leaf low down on the stem, then carry it to the next leaf above, and give it a twist or turn round the base of it, and so on; the nature of the line of connection can then be seen: there is, in fact, a helix which, in passing round the stem, is more or less regular. A horizontal projection of this is called the genetic spiral, and it is best understood in the case of alternate leaves.

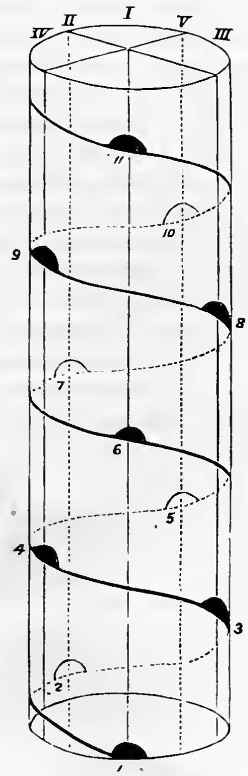

Fig. 5.—Spiral Projection of $\frac{2}{5}$ Arrangement.

It will be necessary to allude here to an expression used in connection with this subject. The term *cycle* has reference to the different leaves which are included in the complete circuit of the spiral—that is to say, those leaves from the first to the one which stands right above it. A technical name is also given to that part of the stem or axis included between one leaf and the next which stands directly over it: this is called the *angular divergence*. Thus, where the leaves are in two rows, the space between two opposite leaves is just one-half of the circle or circumference of the stem, and where there are three rows it is one-third; the expression $\frac{1}{2}$ is applied in the first case, and $\frac{1}{3}$ in the second. The upper figure (numerator) shows the number of turns in the helix, and the lower (denominator) the number of leaves embraced in the cycle. A circle contains 360°; the term $\frac{1}{2}$ indicates angular

divergence equal to 180°, or one-half of 360°; $\frac{1}{3}$ corresponds to 120°, the third of a circle.

In many plants—such as the apple, peach, cherry, poplar, &c.—the leaves present a five-ranked arrangement. Beginning with one leaf, two circuits

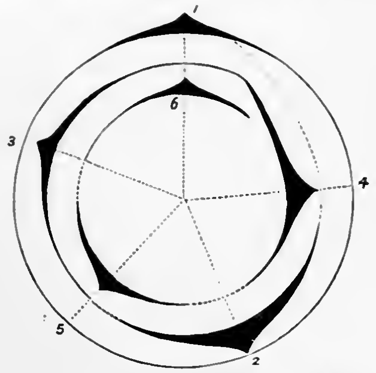

Fig. 6.—Horizontal Arrangement of Fig. 5.

round the stem are necessary before reaching the leaf directly above the one from which the line began. The fraction $\frac{2}{5}$ is used to indicate this—that is to say, two turns round the stem, and the sixth leaf directly above the first; therefore 5 leaves in the cycle. Figs. 5 and 6 show a spiral and horizontal projection of a $\frac{2}{5}$ arrangement.

When we make three turns round the stem before reaching a leaf right above the first, the expression is $\frac{3}{8}$, 3 being the number of turns, and 8 the number of leaves in the cycle.

There are other arrangements, and all may be set down here—$\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, $\frac{13}{34}$, $\frac{21}{55}$, &c.

Now, on examining these expressions, an interesting result comes out—a fraction has its numerator equal to the sum of the numerators of the two preceding, and the same is true of the denominator. One example may suffice. Taking the two first—$\frac{1}{2}$, $\frac{1}{3}$—these by addition give the next $\frac{2}{5}$, and so on. In the series given above, called the primary series, any numerator is the same as the denominator of the fraction next *but one* preceding—for example, the numerator in $\frac{2}{5}$ is the denominator of the first, ¹.

A few examples may be given of plants which show some of these arrangements :—

$\frac{1}{2}$. Gladiolus, iris, grasses, lime, elm, &c.

$\frac{1}{3}$. Birch, orchis, tulip, &c.

$\frac{2}{5}$. Apple, oak, poplar, cherry, &c.

$\frac{3}{8}$. Flax, holly, &c.

$\frac{5}{13}$. Cones of Weymouth pines, eyes or buds on the tubers of potato plant.

$\frac{8}{21}$. Cones of larch and silver fir.

The more simple arrangements are of frequent occurrence; where the internodes are very short, the leaves are crowded, and the analysis of such cases is more difficult, as in the rosettes presented by the leaves of some *sedums* or stonecrops, and of *sempervivum* or houseleek (Fig. 7, $\frac{5}{13}$ arrangement), and the cones of firs. Nevertheless, the general spiral arrangements are in such cases obvious enough; instead of one simple spiral there are several parallel or secondary spirals, more or less numerous. This is best seen in any large, or even small, fir-cone. Some of the spirals run from left to right, others the reverse. In such cases the primary or generating spiral has reference to a full series of the leaves on the axis, the spiral line passing through every leaf; the secondary spirals are only partial—that is, do not embrace every leaf or scale. In such cases, the fundamental spiral cannot be easily followed; but an examination of the secondary spirals will give assistance in this. These secondary spirals vary in

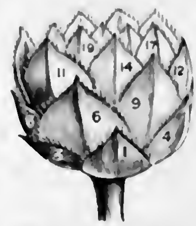

Fig. 7.—Arrangement in the Houseleek.

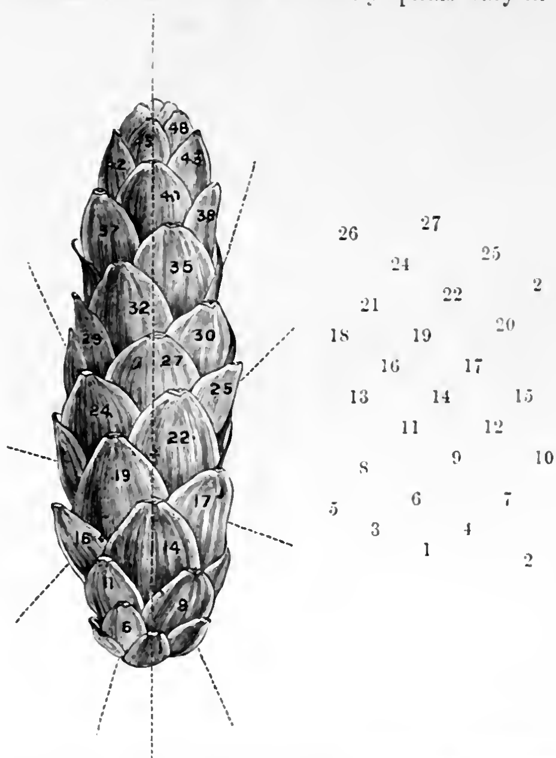

Fig. 8.—The Side of Cone of Weymouth Pine, with Scales numbered, and a Projection of the Arrangement.

number according as the fractional sign of the primary spiral is higher.

The cone of *Pinus strobus*—white or Weymouth

pine—is in various works used to illustrate this subject, and the same example may be adopted here. Fig. 8 represents one side of the cone with the scales numbered, and beside it a projection of the arrangement $\frac{5}{13}$, the normal in this cone, the number 14 being directly above the scale number 1, the cycle consisting of 13 scales, the spirals being 5. A line which passes to the left through the numbers 1, 2, 3, 4, &c., makes five turns round the cone before it ends at 14, directly above 1. There are 5 parallel spirals of the order 1, 6, 11, &c. (these give the numerator), and 8 of the order 1, 9, 17, &c.; then 8 and 5 give 13, so that the primary spiral expressed by $\frac{5}{13}$ may be got from the number ot secondary spirals parallel to one another.

Although the angular divergences of leaves represented by the series of fractions already given, are on the whole constant in individual plants, still it must be noted that there are deviations. Starting from one leaf, and following up the spiral, we may find a leaf vertically over the first, which will give a fraction different from the ordinary one.* Most fir-cones have such arrangements as are expressed by the ordinary terms, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, &c., whose generating and successive secondary spirals are shown by the numbers 1, 2, 3, 5, 8, 13, &c.; but cases occur in which there are either conjugate spirals of the ordinary system, or there are arrangements which may be referred to other systems of spirals. The more common exceptions are bijugates of the usual system, and therefore represented by the numbers 2, 4, 6, 10, 16, 26, &c.; and simple spirals of the system $\frac{1}{3}$, $\frac{1}{4}$, $\frac{2}{7}$, $\frac{3}{11}$, $\frac{5}{18}$, &c., giving the numbers 1, 3, 4, 7, 11, 18, &c. Rarer exceptions are trijugates of the ordinary system, giving the numbers 3, 6, 9, 15, 24, 39, &c., or spirals of the system $\frac{1}{4}$, $\frac{1}{5}$, $\frac{2}{9}$, $\frac{3}{14}$, $\frac{5}{23}$, $\frac{8}{37}$, giving the numbers 1, 9, 14, 4, 5, 23, 37, &c.

Bravais and others have explained some of these abnormal arrangements by supposing partial abortion of one of the spirals, or coalescence of two secondary spirals into one. Professor Dickson's objection to this idea is that secondary spirals are only relative, and he shows that in some cases there is coalescence or union of two consecutive scales of the secondary spirals, giving rise to disturbance, this being really the true explanation. In other cases, it is considered that the ordinary simple spiral, and the ordinary bijugate, are fundamental forms—that is, forms with either of which a cone may commence without the intervention of another. The derivations of the different systems from the one or from the other would thus be a simple matter.

Variations of the angular divergences of the leaves of the Jerusalem Artichoke (*Helianthus tuberosus*) have been examined by the Rev. George Henslow.† He observed transitions from one kind of divergence to another: $\frac{2}{7}$, $\frac{3}{11}$ were not uncommon, and more rarely an approach to $\frac{1}{4}$ and $\frac{5}{18}$. But these can be arranged in a series analogous to the usual one—viz., $\frac{1}{4}$, $\frac{2}{7}$, $\frac{3}{11}$, $\frac{5}{18}$, &c.; that is to say, numerators being the same, the denominators of the successive fractions of the secondary series are equal to the sums of the numerators and denominators of the corresponding fractions of the ordinary or primary series. Mr. Henslow shows that any one series can pass into another if it be represented by a generating spiral, the angular divergence of which is a low one in that series. In the same paper a comparative view is given of fractions belonging to deviations from the ordinary or primary series, thus:—

Primary Series, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, $\frac{8}{21}$, $\frac{13}{34}$.
Secondary Series, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{2}{7}$, $\frac{3}{11}$, $\frac{5}{18}$, $\frac{8}{29}$, $\frac{13}{47}$.
Tertiary Series, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{2}{9}$, $\frac{3}{14}$, $\frac{5}{23}$, $\frac{8}{37}$, $\frac{13}{60}$.

Here the sum of the denominator and numerator of the third fraction of the primary series gives the denominator 7 to the third fraction of the secondary series, and so on; and, as in the primary series, so in the others, the sum of the denominators of two adjacent fractions gives the denominator of the next succeeding.

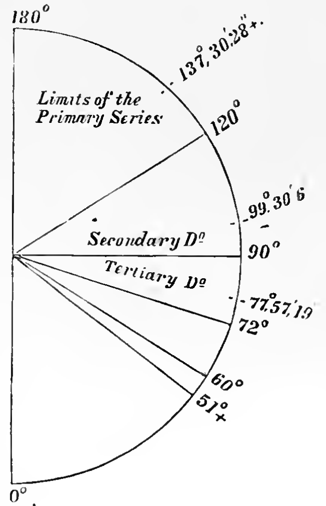

Fig. 9.—Diagram illustrating Mr. Henslow's Theory.

It has been already stated that in the primary series any numerator is the same number as the denominator of the fraction next but one preceding. This relation does not hold in the others; "but if it be remembered that the denominators can be formed by adding the numerator and denominator of the corresponding fraction of the preceding series,

* As has been shown in the case of some Firs by Professor A. Dickson. ("Transactions of the Royal Society, Edinburgh," vol. xxvi.)

† "Transactions of Linnean Society," vol. xxvi.

the true and general relation at once appears." The following are examples:—The denominator of the fraction $\frac{3}{8}$ supplies the numerator to the fraction $\frac{8}{21}$; but in the secondary series the denominator is 11 (*i.e.*, 8 + 3); so also in the tertiary series the denominator of the corresponding fraction is 14—that is, 11 + 3 is equal to 8 + 3 + 3. The fourth fractions may, therefore, stand thus: $\frac{3}{8}$, $\frac{3}{8+3}$, $\frac{3}{8+3+3}$, $\frac{3}{8+3+3+3}$, &c.

Mr. Henslow shows by a diagram (Fig. 9) that "the angular distances included by the limiting positions of the second leaves of all generating spirals, commencing at 0, decrease according as the spirals belong to the secondary, tertiary, or quaternary series; so also does the number of leaves in a single coil increase correspondingly; and, therefore, the higher the series, the more nearly does any spiral belonging to it approach the verticillate condition, provided the internodes be but slightly developed." There appears to be a relation between the folding or mutual relation—technically called *æstivation* or *præfloration*—of the parts of the flower when in bud and the laws of phyllotaxis or leaf-arrangement. In many such flower-buds the arrangements $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$ may be recognised; but to enter into details would necessitate the use of technicalities foreign to the subject of this article.

It may be stated here that in some of the lower forms of plants, such as mosses, ferns, &c., the angle of divergence of the leaf-organ is related to the principle of growth. In the $\frac{1}{2}$ arrangement the cell at the end of the axis is divided into two. When the segmentation or division of the apical cell is in three rows, each new division-wall of the cell at the apex being parallel to the last division-wall but two, two rows of leaves are formed, arranged spirally with the divergence $\frac{1}{3}$. The segmentation, then, of the apical cell has a relation to the leaf-arrangement in Cryptogams—mosses, &c.; in Phanerogams—flowering plants—the same relation does not hold.

It may not be out of place to refer here to attempts having reference to approximate measurements of the mean curves of leaves. The subject has been examined by Mr. W. Mitchell.* Taking an outline of a leaf, he selects a point $\frac{1}{4}$ of the mid-rib from the base, and from that he draws *radii vectores* to the outline, corresponding to equal arcs, into which a circle described round the pole or point is divided. On each side of these primary radii others are drawn at equal distances, and each measured by a scale of equal parts: the accompanying diagram (Fig. 10) of an ivy-leaf will illustrate the method.

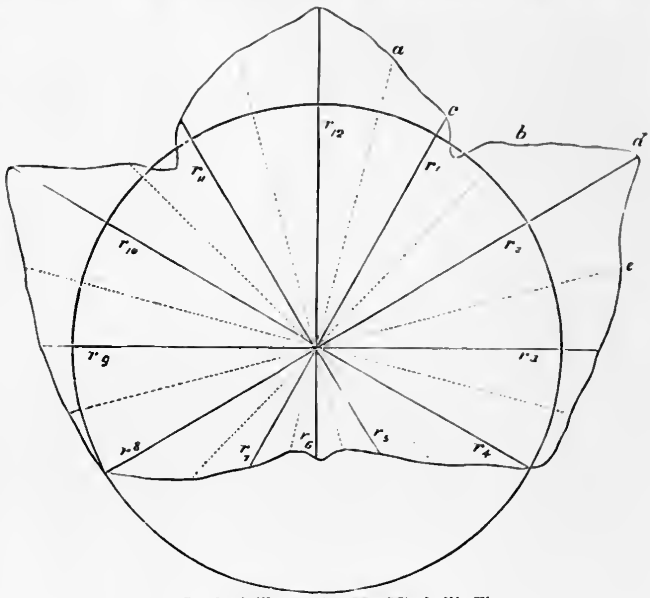

Fig 10.—Ivy-leaf, illustrating Mr. Mitchell's Theory.

The length of each principal radius, added to that of each of the secondary, and the sum divided by the total number, gives a mean radius to each primary division of the circle. It is conjectured that a series of careful measurements made in this way would afford data for comparing the average variation in form of the leaves of any plant, which might lead to numerical relations throwing light on the laws of vegetable morphology. In his second paper Mr. Mitchell treats of equations to the curved outlines of the leaves of plants. He proposes to find formulas to express the curves of the outlines of leaves, so that the calculated values should not differ from the measured, more than the proportional measurements of several leaves of the same plant differ among themselves, by reason of their ordinary variations.

He traces the outline of a well-developed leaf on paper. The base of the mid-rib is taken as the origin of measurement, and from it lines are drawn to the margin, making equal angles with each other. These being measured by a scale divided into tenths of an inch, and the first line or radius vector being longest, we have a descending series of terms from which to construct a formula for the curve in question, in simple, undivided leaves. Little modification is necessary to the more regularly divided leaves, and

* "Transactions Edin. Botanical Society," vols. vi. and x.

to compound leaves. In the 5-lobed leaf of maple, the radiating vein of each lobe may be compared to the mid-rib of a single leaf, and a formula found for 3 out of the 5. The intersections of the curves will produce the outline of the simple divided leaf, when set off on 5 axes, making usually an angle of 45° with each other.

In the simple leaf of laurustinus, the radii for angles of 10° are 34, 26·2, 20, 15, 11, 7·23, 5, 2·6, 0·2, 0, being nearly the same results as by actual measurement—viz., 34, 26, 20, 15, 11, 7, 5, ·2, 0.

Attention may now be directed to the number 4, or a multiple of it in some of the lower forms of plants. The instances are so numerous that a few examples may suffice. It is also worthy of notice that division of protoplasm into two is not uncommon. This is well illustrated in the development of the reproductive spores, as they are called.

The gills of mushrooms are covered with numerous club-shaped cells—sporophores or spore-bearers—on the summit of which the spores are in groups of 4. In others, such as the well-known mushroom called the morell, there are eight spores in an oblong case or cell. In one of our most common sea-weeds, the *Fucus vesiculosus*, or bladder fucus, so-called from numerous air-vesicles on it, the contents of oogonium divide into eight portions (Fig. 11).

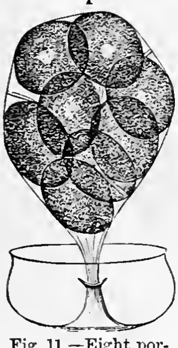
Fig. 11.—Eight portions of Oogonium.

The spores or seed-like organs of mosses, are produced in fours. In the common male fern, *Aspidium filix mas.*, they follow the same law.

This is also illustrated in the development of the grains of the dust-like pollen, which is shaken out of the flowers of the higher plants, or those which have obvious flowers. This is well seen in the earlier stages of the pollen in mallow. After the four very young grains escape from the mother-cell and are free, they increase in size, and the surface becomes rough with projecting points. In some cases the grains, after escaping from the parent cell, even when mature, remain bound together, giving, thus, composite pollen. This occurs in species of typha (cat's-tail) or bullrush. An early stage of the pollen thus remains persistent (Fig. 12).

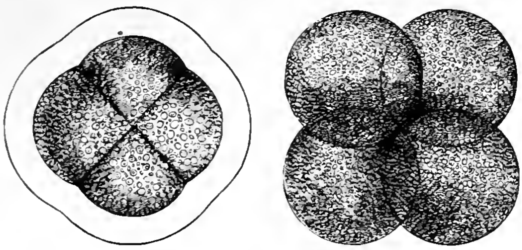
Fig. 12.—Persistent Pollen.

We may finally bring under notice the very notable law which prevails in the number of the teeth which surround the mouth of the ripe capsules or cases which contain the spores of mosses. It may be stated, in passing, that these teeth, forming what is called the peristome, are highly sensitive to moisture, folding over the mouth of the capsule, or unfolding outwards, according to the state of the atmosphere as regards moisture or dryness.


Fig. 13.—Teeth of Tetraphis.

The numbers of these teeth, when present, are 4, or some power of 4 up to 64, being 4 in tetraphis (Fig. 13); 8 apparently in some species of orthotrichum (Fig. 14); 16 in grimmia and others; in zygodon, the outer teeth are considered to be of 32 primary divisions, united 2 or 4 together, so as to represent 16 or 8 plain teeth. In polytrichum there are 64 (rarely 32) teeth. Where there are two rows of teeth, which is a frequent character, the law also prevails, and those of the one row alternate with those of the other.

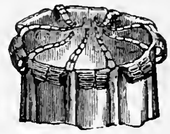
Fig. 14.—Teeth of Orthotrichum.

If we examine the parts of the flower in the higher orders of plants, we observe also that certain numbers prevail, but they are less constant. In those which are called monocotyledonous, in which there is apparently one lobe in the seed, the three-ranked arrangement prevails, as in crocus, iris, tulip, &c. The four and five-ranked, on the other hand, are most frequent among dicotyledonous plants. Fuchsia, epilobium, &c., have the whorls of the flower in groups of 4. In primroses, and many others, the number 5 prevails—that is, the quinary; among them, however, there are some exceptions, the number 3 being seen in magnolia, barberry, &c. As an example of the three-ranked arrangement in the monocotyledonous division, we may take the flower of a hyacinth; we observe on the outside 3 parts, or "sepals" as they are called, forming the "calyx" or cup. More internally, we see other 3 —the petals—the corolla, or coloured part of the flower. Next we find 6 "stamens" in two rows, an outer and inner, and in the centre of the flower a seed-vessel of 3 pieces conjoined; all these alternate with each other. The same succession of parts may

be observed in complete flowers of dicotyledons, the numbers in each whorl being, however, mostly 4 or 5, although there are exceptions to this.

It seems to be a fair conclusion, from structures and arrangements here recorded, that in plants, whether high or low in the scale, certain principles regulate the number and arrangement of different organs, and that even in what is popularly considered to be "admirable confusion," the mighty "reign of law" prevails.

HOW THE WIND CHANGES.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.,
President of the Meteorological Society.

In an article entitled "Why the Wind Blows" (Vol. I., p. 321), the drifting along of air, or, in other words, "wind," was traced to the influence of weight, and to the modifying agency of varying heat. Warm air, being relatively light, is displaced from the position in which it would otherwise rest by the pressure against it of the heavier air seeking to settle down as low towards the earth's centre as it can get. The cold, dense air flows along the descending slopes of the ground very much as water streams along the descending channels of rivers towards the yet deeper depressions of the sea. The flowing air is recognised as wind because it strikes against projecting objects that stand in its path. It is *felt* as wind when those objects happen to be living creatures so organised as to be conscious of the mechanical pressure that is exerted upon their bodies.

But living people who stand in the path of a current of flowing air, or wind, not only feel the pressure of its movement, but also perceive the direction in which the air-current flows. It is felt to be exerting its pressure upon them from one particular side, and it is found that the direction of this pressure is not at all times the same. The wind *changes* its course from hour to hour. At any one station it blows from the south at one time, and from the east, or north, or west, upon other occasions; and it is not at all a difficult matter to understand why this must be the case. It is quite as possible to trace the mechanism by which the wind is made to change its course as it is to comprehend why it blows at all.

One of the simplest, and therefore most intelligible, instances of the changing of the wind is that which is almost constantly met with along any extended stretch of sea-coast in the middle of summer. It is there found that during the hottest period of the day the wind almost certainly blows in from the sea to the land; but that during the cooler hours of the night the wind changes its direction, and blows back from the land to the sea. There are sea-breezes during the day, and land-breezes during the night. The reason for this change is a very obvious one. During the day the land gets more heated than the sea. It retains all the heat of the sunshine very much on the spot where it falls, whilst the sea drinks in, diffuses, or spreads a similar amount through a large bulk of water. If a hand be laid upon the ground, or the sand of the sea-shore, on a bright, sunny afternoon, it will be almost scorched by the high temperature which has accumulated from the blazing sunshine; but if the same hand be plunged into the water of the neighbouring sea, no such burning heat will be felt. The air which rests upon the heated land is, in consequence, warmed by contact with it, and expands and becomes light; and the heavier air which is floating over the cooler sea, not being warmed and expanded to the same extent, presses with its greater weight in upon that which rests over the land, and drives it out of the way. The air-movement is from the place where the pressure is greatest to the place where the pressure is least—that is, it is from the sea to the land.

After the setting of the sun, however, the heated land very rapidly scatters back into space the warmth which it has accumulated. But the sea does not dissipate its heat in the same rapid way, because it holds what it has received back in the deep recesses of the water. In a comparatively short interval of time, therefore, the land gets colder than the sea. The air over the land then ceases to be expanded and made lighter than that over the sea. The land air being thus heavier than the sea air, and the movement of the wind being necessarily from the place where the pressure is great to that where it is less, the breeze blows from the land to the sea. To any person standing upon the sea-shore it becomes at once evident that this is the true state of the case; for the sea-breeze is felt to be deliciously cool and fresh as it blows in upon

the skin during the hot hours of the day; and the land wind is no less cool and pleasant at night as it comes off towards the sea. It is the cool, and therefore heavy, air which moves in, in each case, although it arrives from quite opposite directions.

In some parts of the earth, however, the land gets so much heated up by the rays of the mid-summer sun, that no material cooling is effected all night; the breeze then goes on blowing strongly in from the sea towards the land both day and night, for several days, and even weeks, at a time. This especially occurs, for instance, along the shores of the Indian Ocean from April to October. In this region of the earth the land lies to the north of the equator, as may be seen by a glance at the accompanying map of the Eastern Hemisphere of the earth (Fig. 1), whilst to the south of the equator there is an equally continuous stretch of sea. From April to October, therefore, the land to the north of the equator gets fiercely heated up by the torrid sunshine, and a very strong wind in consequence is brought in from the sea. From October to April, on the other hand, the sun shines more intensely over the ocean, which is on the south side of the equator, than over the northern land, which, in its turn then, does part with more heat by night than it receives during the day. The wind, therefore, at this season, blows with similar steadiness and persistence in the opposite direction, or from the land to the sea. These periodic winds, which are thus changed in their directions by the seasons of the year, instead of by the mere alternating influence of day and night, are called "monsoons"—a word derived probably from the Arabic term *maasaan*, which signifies "season." Attention was drawn to these periodic season-winds of India, in the first instance, during the earlier years of human history, on account of their prevalence along the at that time well-occupied Indian and Arabian coasts, and on account of the abundant fertilising moisture which they carried in to the countries of India during the hot months of summer. These winds also became known to the Greeks at the time of the military expeditions of Alexander the Great to India.

During the prevalence of the greatest heat of the Indian summer, the monsoon winds blow with great intensity and violence, very much as a stronger draught rushes up the chimney of a room when there is a very fierce fire burning in the grate. There is also a tendency to the occurrence of storms and tempests when the monsoon changes the direction of its blowing, on account of the disturbance which is then brought about where the antagonistic and conflicting air-currents meet. But this is a result of the breaking up of the monsoon, as the occurrence is called, which may be more conveniently alluded to in connection with another branch of the subject, which will deal more particularly with the mechanism of hurricanes.

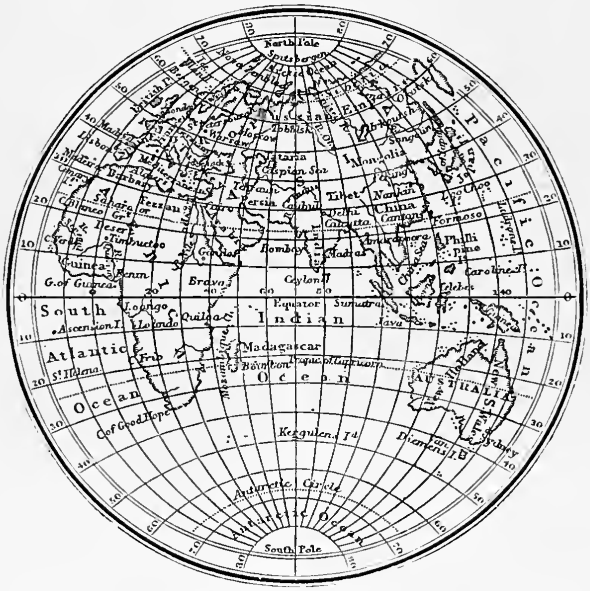

Fig. 1.—Map of the Eastern Hemisphere.

One peculiarity in the movements of the monsoon is, however, deserving of notice here, on account of the light which it throws upon the behaviour of more capricious and variable winds. The general set of the Indian monsoon in the summer months is from the sea to the land — that is, from the south towards the north; and in the winter months, so far as there can be said to be any winter in India, the general current is from the land to the sea—that is, from the north towards the south. But as a matter of actual fact, the monsoon blows during the Indian summer towards the east as well as towards the north; and in the opposite season towards the west, as well as towards the south. The monsoon is a south-westerly wind in the summer, and a north-easterly wind in the winter. This deviation of the air-currents in a westerly or easterly course is a natural and necessary result of the circumstance that the earth is itself continually spinning round from west to east as it moves along in space. As the earth spins round upon itself, its surface carries along

with it, as a mere consequence of frictional adhesion, the superincumbent investment of air. Thus, whilst the air is flowing from the equator towards the north under the influence of the superior weight and pressure of the colder atmospheric mass, it is at the same time continually carrying with it its great equatorial velocity to a part of the earth where, the circle of rotation being smaller, the velocity of rotation is less. The air thus has a tendency, when it reaches the circles of narrower dimensions, to overshoot the rotatory progress of the terrestrial surface beneath—that is, it goes faster in an eastward direction than the ground or sea beneath, and to any object attached to that ground, or partially immersed in the sea, its eastward preponderance of movement is perceptible as well as its northward flow. On the other hand, when the wind comes in towards the south from the more northern land, it finds the ground or the sea moving faster towards the east than its own momental impulse is carrying it, and it consequently lags back in reference to the onward movement of the ground, or sea, and thus has an apparent westward, as well as an actual southward, drift, or flow.

A glance at the map of the Eastern Hemisphere of the earth (Fig. 1) will materially assist the reader in understanding this complication of movement. It will be observed, on referring to this map, that the space between the 60th and 70th meridians on the equator is twice as long as it is on the 60th parallel of south latitude. If, therefore, a mass of air which was being carried along with the earth's surface towards the west at the equator were suddenly transferred to the 60th parallel of latitude, taking its equatorial velocity of rotatory movement with it, it would overshoot the movements of the sea or ground, and get 20°, or an 18th part of one rotation of the earth, on, whilst the surface beneath, whether sea or ground, only advanced 10°, or a 36th part of one rotation. This is exactly what occurs, although in a very much smaller degree, when a northward moving wind in the northern hemisphere acquires an eastward set in consequence of the rotation of the earth.

The wind thus blows along the surface of the earth from places where the air-pressure is great to places where the pressure is small—that is, from places that are cold to places that are warm. But it also *changes the direction* in which it blows from time to time, because the positions of greater and less heat are themselves shifted about upon the surface of the earth, under the changing conditions of sunshine and cloud, and under the irregular distribution of water and land, and of mountains and plains. On account of the movement of the earth, turning as the vast sphere does from day to day in front of the sun, with its axis of rotation held inclined to the plane of its forward journey, in one unvarying direction, the sun blazes down upon the terrestrial sphere with greatest intensity of heat, now here, and now there, and the wind, as a matter of course, changes the direction of its blowing to follow the wandering path of the shifting and fitful sunshine.

That the changing of the direction of the wind is due to the shifting of the situations of greatest heat upon the earth is substantially proved by the fact that in certain regions of the terrestrial surface, where the situations of greatest heat and cold do not alter the direction in which they lie to each other, the wind does not change, but blows always in the same direction from one day to another, and all the year round. This occurs in the great open spaces of the ocean, where there is no land to get heated up by the sunshine of the day, and to get cooled by the scattering of the heat at night. In those spaces for a vast breadth of many hundred miles the sun shines down day after day upon the surface of the sea, heating the water most along the mid-ocean track which lies most immediately beneath its burning rays, as it passes across from east to west. This midway track of the strongest sunshine crosses the wide ocean as a belt or zone, that spreads some way to either side of the equator. Throughout this midway track the cooler and heavier air on either hand drifts in from the north and from the south, and then rises up, as it becomes heated by the sun, where the two currents meet. In both instances, however, in consequence of the spinning round of the earth, the advancing wind acquires a westward as well as an equatorial drift. The air-current, as it approaches the midway equatorial zone, where the onward movement of the sea-covered surface of the earth is performed with the vast velocity of a thousand miles an hour, does not immediately acquire this full rate of speed, and lags back upon the ocean, so that it appears as a drift towards the west, as well as towards the equator. On the north side of the equator the wind blows all the year round from the north-east, and on the south side from the south-east, both in the Atlantic and Pacific Oceans. These steady and unchanging ocean winds are called the trade-winds, on account of the great service they render to

ships carrying merchandise across these portions of the sea. In sailing from England to the Cape of Good Hope, through the entire length of the Atlantic Ocean, ships, before they reach the equator, have to pass over a broad space, where strong winds are always blowing steadily from the north-east. That is the region of the north-east trades. They then traverse a space near to the equator itself, where the north-east wind ceases to blow, and where the air is very still and calm, and they afterwards come to a region to the south of the equator, where strong winds are continually blowing from south-east. That is the region of the south-east trades.

The district of calms which intervenes between the north-east and south-east trades is the place where the opposite currents meet so as to neutralise each other's movement, and then rise bodily up as masses of sun-warmed and rarefied air, into the higher regions of the atmosphere. The trade-winds prevail for a breadth of nearly three thousand miles of the Atlantic Ocean, between the west coast of Africa and the east coasts of America; and for a breadth of ten thousand miles of the Pacific Ocean, between the west coasts of America and the large Asiatic islands lying to the South of the Chinese Sea (Figs. 1, 2). Between these Asiatic islands and the east coast of Africa (see Fig. 1, p. 14) there is another stretch of sea, which is three thousand miles wide, and which is known as the Indian Ocean. But this is the part where the monsoons, or periodical season-winds, prevail, because the great land-stretch of India and Arabia, instead of an open ocean, there lies to the north. In that part the north-east monsoon of the winter season is, it will be observed, in reality the trade-wind as well as the monsoon. The summer monsoon only is a reversal of the natural current of the trade-wind at the time when the land of India and Arabia, and of Central Africa, becomes most fiercely scorched by the sun. In the winter of India the north-east trade-winds are simply increased in force, in the Indian Ocean, by the addition to them of the monsoon, or season influence, acting in the same direction. During the summer of India, the north-east trade-winds are stopped in the Indian Ocean, and then ultimately reversed, by the superior power, at that time, of the sun-scorched land to produce an in-draught. From this steady and unvarying movement of the air over the broad open spaces of the equatorial oceans, it appears, therefore, that it is not *only* the differently heating power of the sun in different parts of the earth which produces the blowing of the wind; but that the spinning movement of the earth, which never varies and never stops, has also to do with it. As the vast terrestrial globe spins round in space, all bodies that are held upon its surface by the attraction of the terrestrial mass go round with it. But such of those bodies as have free movement amongst their own particles, as is the case with air, do not travel with it at an equal pace, but linger behind when they are streaming from parts of the earth where the rotatory velocity is small towards parts where it is greater; or, on the other hand, overshoot the movement of the more rigid portions of the earth when they stream from parts where the velocity is great, to parts where it is less. The movement of the wind is *not only* from spots where the atmospheric pressure is great to parts where it is small, but it is *also* in the direction in which the air is whirled by the rapid and never-ceasing gyration of the earth. North winds in the Northern Hemisphere, and south winds in the Southern Hemisphere, veer more and more towards the west, or into the direction which is opposite to that in which the solid superficial mass of the earth itself is advancing, the more strongly they blow. This westward impulse is also more predominantly marked in the regions of greatest equatorial velocity than it is along the narrower circles of the spinning earth, and it is more readily and frequently interfered with by

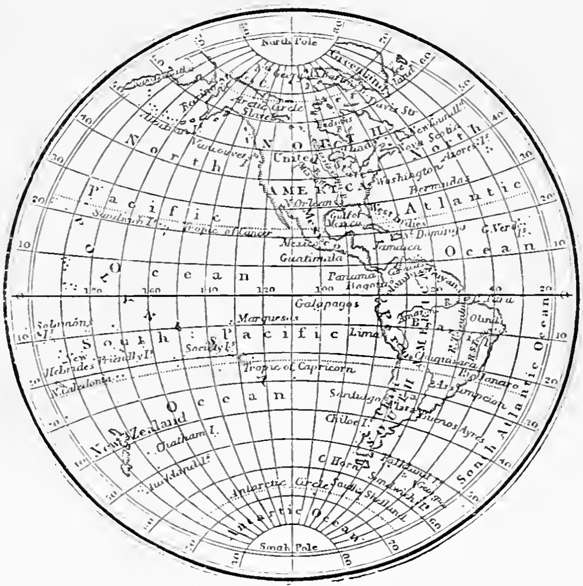

Fig. 2.—Map of the Western Hemisphere.

other and disturbing influences in the regions which are most remote from the zone of most rapid rotatory movement. On account, therefore, of this secondary impulse, which is referable to rotation, there is more west wind than east upon the surface of the earth. Over a very large portion of

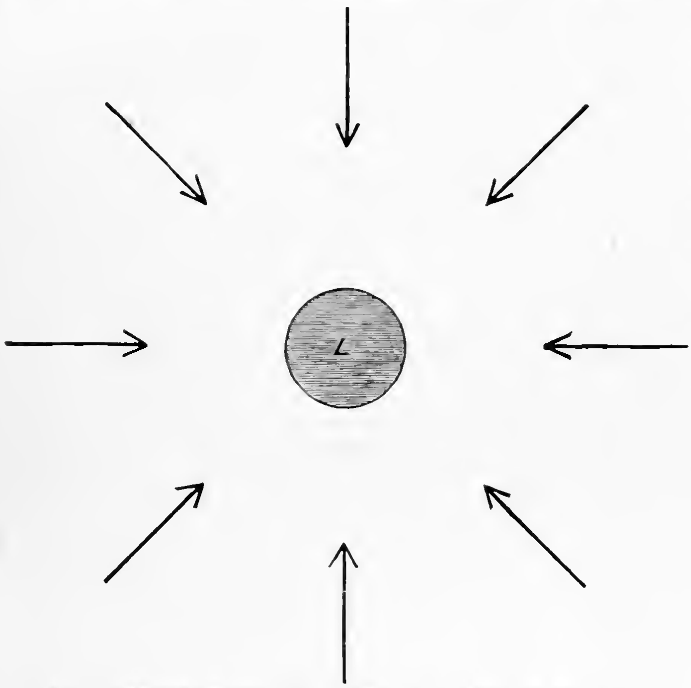

Fig. 3.—Showing Movement of Wind towards a Spot where the Atmospheric Pressure is very low.

Europe, where the observation has been most carefully made, it is found that there are a considerable number more of days on which the wind blows from the west, or south-west, than of days on which it blows from the opposite points of the compass. It has been calculated, indeed, that at least one-half of the movements of the winds may be attributed to the impulse which the air receives from terrestrial rotation.

The trade-wind regions of the earth, where the wind does not materially change the direction of its blowing, not only extend two-thirds of the way round the circumference of the globe across the vast breadths of the great oceans, but they also stretch, in each case, 1,500 miles from north to south, with a calm belt of from 300 to 400 miles between. Vessels sailing from north to south thus have to pass through 3,000 miles of trade-wind, and 350 miles of calm, before they get into parts of the ocean where variable winds prevail. The regions of the trades shift a little up and down in the direction of latitude at different seasons of the year, because they follow, to some small extent, the shifting of the position of the vertical noonday sun, which is farther north in the summer of the northern hemisphere of the earth, and farther south at the opposite season. This, however, and the increased westward set, in approaching more nearly to the line of high equatorial velocity of rotation, are the only traces of vacillation, or uncertainty, which these steady and unchanging winds exhibit.

The unceasing whirl of the earth as it moves along in its majestic sweep through space is thus a cause of a steady drift of the air along the terrestrial surface, and that drift is swayed, now in one and now in another direction, by the influence of unequal atmospheric pressure, which tends constantly to throw the air-drift from the regions of greatest towards regions of least density and weight. The actual course of the wind is, consequently, due to the combined influence of the two causes. But of these causes the one is itself a shifting force, depending on the varying relations of the sun. It follows that luminary in its daily march through the sky, and in its annual course connected with the seasons. It also relates itself to the diversities of land and sea, and it hangs upon the vicissitudes of sunshine and cloud. The operation of the wandering and unstable power consequently tells in the frequent reversal, or bending, of the current of the air at any one place. It is the effective source of the changing of the wind. Thus, if L in the diagram (Fig. 3) represented a spot upon the earth where the pressure of the atmosphere was very low

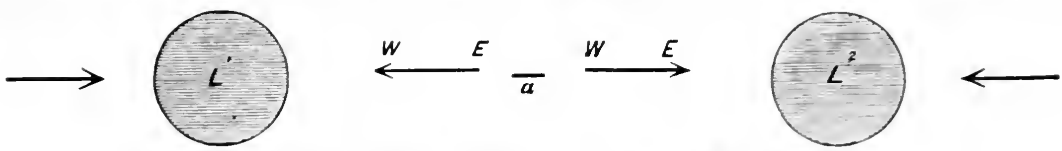

Fig. 4.—Showing Movement of Wind when the Area of Pressure changes.

in consequence of the air having been there greatly heated by the sun, the movement of the wind from all directions around would be in towards that space, as indicated by the pointing of the arrows. If the spot L of low pressure were, however, drifting along, and shifting its place, the consequence to any one standing still on the ground where it passed would be that the current of the wind would change to him, although it might still be blowing on towards the centre of low pressure. Thus, if the low pressure were at L^1 in Fig. 4, the movement of the wind to a person standing at *a* would obviously be from E to W—from east to west. But when the area of the low pressure had drifted on from L^1 to L^2, the movement of the wind to the person standing at *a* would as manifestly be from W to E—from west to east. The mere drifting along of the region of lowest pressure would thus, in effect, change the direction of the wind to the person stationed at *a*.

As a matter of fact, the regions of low and high atmospheric pressure upon the earth never do stand still over one place. They are always drifting along and changing their position, and carrying the air-currents with them, and about them, as they drift. But more than this. In consequence of the air itself being a very elastic and movable gaseous substance, and in consequence of the balance never being very exactly and evenly sustained where the greater and less pressures meet, there is a constant tendency of the movement of the air to bend itself into curves, and to whirl round into eddies, much like the eddies which are formed where antagonistic currents of water encounter each other in rapidly flowing streams. The wind rarely blows along in straight lines, and almost always whirls round into eddies, and the more fiercely the wind blows the more strongly marked these great eddies become. In the fiercest winds, or hurricanes, they constitute what are at once recognised as "whirlwinds."

It is yet again a natural consequence of the spinning roll of the earth that this eddying movement of the winds always inclines to take place in the same direction. The air-drift occasioned by the earth's roll in the end preponderates over all impulses in other directions, or from other causes. Even the changes of the wind are reached by this dominating influence. In the northern hemisphere of the earth the change of direction commonly takes place from north *through east* and south, to west; and in the southern hemisphere, from north, *through west* and south, to east. In England an east wind almost always follows a north wind, and then passes on to a wind from south and west, and back again from north. This regular order in the shifting of the wind was first accurately observed about forty years ago, by Professor Dové, of Berlin, and has thence been since associated with the name of that meteorologist, until it has finally come to be spoken of as "Dové's law." The period which is occupied by the wind in passing through this cycle of changes is of uncertain length, and often occupies many days; but the same series of changes invariably begins over again when one cycle has been made complete.

The heavier air setting in towards the region of least atmospheric pressure thus whirls round and round where the air-currents meet in a central spot. But as it is in that spot that the air-weight is least, it is there, as a matter of course, that the light air is driven up. For a considerable space it is pressed directly up towards the clouds, and towards the still higher regions above, and it then flows over and back, to fill up the space from which the heavier air below has advanced. That, therefore, is what becomes of the air which flows in by its greater weight from all directions around. It gets warmer and lighter in that central spot, and then ascends straight up out of the way of the heavier cold currents that are still coming in upon the same track.

The velocity with which the wind blows mainly depends upon the strength with which the warm light air is pushed out of the way by the heavy cold air pressing in to take its place; or in other words, it is in proportion to the difference of the weight of the heavy and light air, and to the distance from each other at which the centres of greatest and least pressure are situated. Thus, if, in Fig. 5, O represents the

O . . . . 500 Miles L

45 Miles an Hour.

Fig. 5.—Illustrating the Velocity of Wind.

position of the Orkney Islands, in the North Sea, and L that of London, some 500 miles away, and if it be conceived that the barometer at O is indicating an atmospheric pressure equivalent to one inch of mercury more than that which is shown by the barometer at L, then the movement of the wind between O and L—between the Orkneys and London—would be something like 45 miles an hour. But if, on the other hand, the difference of one inch of pressure occurred between London and Morpeth, in Northumberland, a place that is about midway between the Orkneys and London, and therefore 250 instead of 500 miles from London, the movement of the wind between Morpeth and London would be at the higher velocity of 63 miles an hour. To halve the distance at

which any given difference of pressure acts is tantamount to increasing to some definite degree the velocity of the movement of the wind. The same effect is, however, also produced if, instead of diminishing the distance of the sites of high and low pressure, the difference of pressure is increased. A barometer indicating a pressure of two inches of mercury more at the Orkneys than in London would almost certainly be accompanied by a wind moving between the Orkneys and London with a velocity of 63 miles an hour. This is a very important fact, and it is the circumstance which has led to the adoption amongst meteorologists of the term "barometric gradient," a form of expression first used some twenty years ago by Mr. Thomas Stevenson, the distinguished engineer.

This designation signifies that the difference of pressure between the two remote places may be conveniently expressed by a line drawn from the one to the other in such a way as to indicate the steepness of the slope or gradient, by which the air-pressure increases during an advance from the one station to the other. Thus in Fig. 6, if the

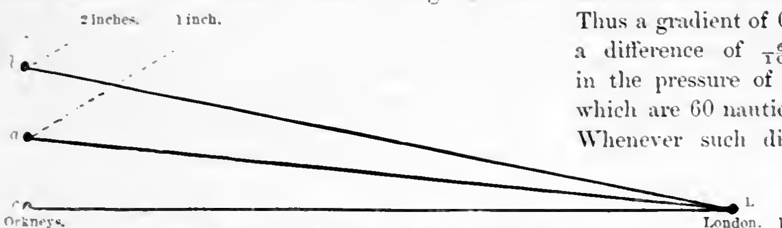

Fig. 6.—Illustrating the "Barometric Gradient."

angle *a* L O expressed the steepness of the gradient when the pressure was one inch of mercury more at the Orkneys than in London, then the larger angle *b* L O would express the steepness of the gradient when the pressure was two inches of mercury more at the Orkneys than in London. Or again, if the angle *a* L O, Fig. 7, expressed the steepness

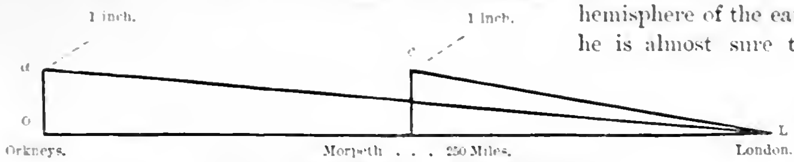

Fig. 7.—Illustrating the "Barometric Gradient."

of the gradient when there was one inch of pressure more at the Orkneys than in London, then the larger angle *c* L O would express its steepness when the inch difference of pressure occurred between London and Morpeth, the station only half the distance of the Orkneys away. In either case, the angle would be twice as large; or in other words, the gradient would be twice as steep in the second instance as in the first. The barometric gradient constructed in this way becomes a very useful expedient to indicate what the velocity or force of wind is that may be looked for between stations at which the difference of barometric pressure is known. The steepness of the gradient, it will be observed, takes into consideration *both the elements*—the distance of the two stations asunder, and the difference of atmospheric pressure on the two. The greatest velocity of the wind is, however, found really to occur about midway between the spots where the greatest and least pressures lie. The wind increases its velocity as it flows from the place where the air-weight is greatest towards the place where it is least, until it gets half-way, and it then begins to moderate and reduce its speed. Scientific meteorologists have agreed to consider 60 nautical miles as a sort of unit, or standard of distance, when barometric gradients have to be spoken of; and they then express the steepness of the gradient in figures, which give the differences of pressure for that distance in hundredths of an inch of mercury. Thus a gradient of 0·06 means simply that there is a difference of $\frac{6}{100}$ths of an inch of mercury in the pressure of the atmosphere at two places, which are 60 nautical or 69 statute miles asunder. Whenever such difference of pressure exists at stations thus far apart, it is tolerably certain that a strong breeze is blowing between. A strong gale is seldom, if ever, experienced over the British Islands, unless the difference of barometric pressure at remote stations within their range amounts to at least half an inch of mercury.

One practical consequence of the influence of the earth's rotation upon the movement of the wind is that whenever an observer stands on the northern hemisphere of the earth, with his back to the wind, he is almost sure to have a lower atmospheric pressure on his left hand than on his right. The wind, as a matter of fact, blows not in a straight line from the place of greatest atmospheric pressure to the place of the least, as it would if its course were not modified by the secondary influences which have been dwelt upon, but in a curved line, sweeping whirlingly round the area of least pressure in one unvarying direction. This, in its simplest form, is the statement of the meteorological law which was first established by the Dutch

meteorologist Buys Ballot, who resides in Utrecht, and there superintends the weather observations of that place. This circumstance, that the area of low pressure, towards which the wind inclines to blow, is to the left hand of an observer who stands with his back to the wind, is now universally known as "Buys Ballot's law," and it is a very important condition in meteorological science.

When the wind does not blow with a velocity as great as three miles in the hour, the movement of the air can scarcely be perceived by a person standing in the current, and it is consequently considered that the atmosphere is in the state which is characterised as "calm." The wind which is perceived as a gentle breeze moves with a speed of from 13 to 18 miles in the hour. A wind moving at the rate of 35 miles an hour is felt as a strong breeze. A velocity of 50 miles an hour constitutes a gale. Storm-winds travel at the rate of 75 miles an hour, and fierce hurricanes blow at the rate of from 90 to 100 miles in the hour. A wind travelling at the rate of 3 miles an hour presses with a force of about three-quarters of an ounce upon every square foot of surface which stands in its way. A wind of 18 miles an hour gives a pressure of one pound and a quarter on each square foot. A wind of 35 miles an hour gives a pressure of 6 pounds on the square foot; a gale of 50 miles an hour of 13 pounds, a storm of 75 miles an hour of 28 pounds, and a hurricane of 90 miles an hour of something approaching to 40 pounds on the square foot. This matter of the pressure which may be mechanically exerted by winds of high velocity has necessarily to be very carefully taken into account by architects and engineers in planning the strength of buildings.

DREAMS.

By Robert Wilson, F.R.P.S.,

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THOUGH, according to Shakspere, "we are the stuff dreams are made of," yet we know extremely little about the process of their manufacture. "The reason why" lies on the surface. The phenomena of dreaming—that is to say, all that we can find out about the matter by personal discovery—lie for the most part beyond the sphere of conscious observation. Hence, in studying the subject, we have to fall back on our recollection of what in our own experience dreaming was like, how it affected us, and what impressions it left behind. The professors of mental science have always been reproached because they employed the introspective method, or that of self-examination, for purposes of investigation, it being alleged that one is always apt to fall into dangerous fallacies when he makes himself or his own nature the object of critical study. But in the case of dreams we are not only in the main obliged to use this unsatisfactory mode of research, but we are burdened with this additional disadvantage, that we are subjecting for self-examination the actions of our mind not in the waking, but in the sleeping state. If it is hard to analyse mental operations which are going on whilst we are awake, it is doubly hard to do so efficiently when these take place during a temporary suspension of consciousness. This much it is necessary to say, lest complaint be urged that, even after the best-directed efforts to peer into the mystery of dreams are made, only a scanty show of positive and indubitable knowledge can be exhibited. Still, even a little knowledge, if it be of the positive and indubitable kind, is worth volumes of speculative conjecture, as may be cogently reasoned out by comparing the ancient with the modern doctrine of dreaming. The sources of our information, then, about dreaming are introspective memory, and what people who are awake can decipher of the slumberer's mental manifestations.

Perhaps the best way to define the meaning of the dreaming state is to do it negatively. Sleep, everybody knows, is not always blank oblivion. When it is not, and when the sleeper is more or less conscious of a certain variable and fluctuating amount of mental activity, of which he has an uncertain remembrance, he is in the dreaming state. The chief features of this condition can hardly be unfamiliar to any thoughtful or observant person. A current of thought rushes through the sleeper's mind, but it does so, as a rule at least, free from all voluntary control. The mind runs riot in a mad world of phantasy, and, conjuring up scenes, incidents, and persons, groups them into a grotesque

mosaic of dramatic improbability and incoherence. The absence of the regulating influence of the will, and of the assorting and selecting processes by which the mind usually arranges its ideas into intelligible and rational combinations, of course leaves the sleeper at the mercy of mental association and suggestion. Another remarkable peculiarity of dreaming is that in this state the mind, though active, is almost completely withdrawn from relation to the external world. In spite of this, however, the sleeper perceives things as vividly as, usually more vividly than, he would do were he awake. In fact, a dream is both a mystery and a miracle, for in it we may see things which are not, and hear sounds whose vibrations never penetrate the cavernous recesses of the ear. Images that would be usually producible only by external objects are actually created by our minds whilst they are lulled in sleep, and without these external objects being present to evoke them. Sleep has been called the brother of Death. Working in the same vein of fancy, we might say Dreaming was the cousin-german of Madness. Insanity, it is true, gives rise to hallucinations quite as wild as any that course through the dreamer's brain. But there is just this difference between insanity and dreaming—that in the former state the mind is not cut off from the external world, because sleep has not closed what the late Dr. George Wilson felicitously called "the five gateways of knowledge." In the dreaming state, on the other hand, the mind, as we have seen, is shut off almost completely from the external world.

Another extraordinary peculiarity of dreaming to which scientific men have directed special attention is the solid reality, or, to use the harsh technical jargon of psychologists, the "vivid objectivity" of dream-pictures or images — indeed, these images, when remembered, appear even more vivid than do those produced in our waking moods. The dreamer actually sees objects and hears sounds; in fact, the very commonest term applied to dreams ("visions") illustrates this odd peculiarity. Ocular perception, the result of impressions made by actual solid material objects, is the most conspicuous phenomenon in dreaming. There is thus an unconscious aptness in the popular application of the word "vision" to designate a dream, which is at least worth noting. From what has now been advanced, it may be inferred that it is possible—nay, even easy—to distinguish between dreaming and imagining. We can conjure up in fancy the image of an absent friend. But if that friend suddenly enter the room, we find we have a very different notion of him from that conveyed to us by our imaginative faculty. The dreamer has a deeper imprint made on the tablets of consciousness than the mere shadowy impressions left on the mind by an effort of fancy. The dream image is, in fact, not only as vivid as, but, when remembered, more vivid than, that printed on the brain by the real material object which it represents, and which gives rise to it in the waking or conscious state.

Who does not from reading know about innumerable instances in which the vividity of empty dream-fancies excelled that which would be evolved by actual realities? Coleridge, for example, after reading the famous passage in "Purchas's Pilgrims" referring to the building of Khan Kubla's palace, did not see it as a vague, shadowy object reflected in the dim mirror of the imagination. He actually saw, as a solid object, Kubla Khan's "stately pleasure dome," where

> "Alph, the sacred river, ran
> Through caverns measureless to man,
> Down to a sunless sea."

He even saw as a reality—

> "The shadow of the dome of pleasure
> Floated midway on the waves,
> Where was heard the mingled measure
> From the fountains and the caves."

And he saw it vividly enough to know that—

> "It was a miracle of rare device,
> A sunny pleasure dome with caves of ice."

Indeed, of the poet's dream we have his own curious record. The words in "Purchas's Pilgrims,"—"Here the Khan Kubla commanded a palace to be built, and a stately garden thereunto; and thus ten miles of fertile ground were enclosed with a wall,"—had hardly passed through his mind, when he fell asleep and dreamt. He says he "continued for about three hours in a deep sleep, at least, of the external senses, during which time he has the most vivid confidence that he could not have composed less than from 200 to 300 lines; if that, indeed, can be called composition in which all the images rose up before him as things with a parallel production of the correspondent expression, without any sensation or conscious effort."

Dr. James Gregory, when he went to bed one night with a warm-water bottle to his feet, actually felt in his dream the hot crater of Mount Etna burning beneath his tread. So, again, Dr. Reid, the Scottish metaphysician, when he had a blister on his head, positively endured all the physical torture of being scalped whilst dreaming that he had fallen into the hands of a party of Red Indians. Months before Burke, the Edinburgh murderer,

was arrested and convicted of his crimes, unquiet dreams had revealed his fate to him. He had indubitably seen from his scaffold the upturned faces of the savage mob gazing fiercely upon him as he stood under the gibbet. Perhaps the most striking example of dream-realism on record, is the following related by Dr. Abercrombie, of an officer, "whose susceptibility of having his dreams thus conjured before him was so remarkable that his friends could produce any kind of dream they pleased by softly whispering in his ear, especially if this were done by one with whose voice he was familiar. His companions were in the constant habit of amusing themselves at his expense. On one occasion they conducted him through the whole progress of a quarrel, which ended in a duel; and when the parties were supposed to meet, a pistol was put into his hand, which he fired off in his sleep, and was awakened by the report." Connected with this peculiarity of vivid objectivity are the strange freaks of exaggeration and expansion with regard to the dimensions of Space and Time which the mind perpetrates during the dreaming state. The narcotic slumbers of De Quincey were haunted by dreams in which he tells us "the sense of space, and in the end, of time, were both powerfully affected. Buildings, landscapes, &c., were exhibited in proportions so vast as the bodily eye is not fitted to receive. Space swelled and was amplified to a sense of unutterable infinity. This, however, did not disturb me so much as the vast expansion of time; I sometimes seemed to have lived for seventy or one hundred years in one night—nay, sometimes had feelings representative of a millennium passed in that time; or, however, of a duration far beyond the limits of human experience."

This faculty of expanding time, so that a moment will become a month, or a year, or a decade, is capable of boundless illustration. In a dream which could not have extended over an hour, Dr. Macnish says, "I made a voyage, remained some days at Calcutta, returned home, then took ship for Egypt, where I visited the cataracts of the Nile, Grand Cairo, and the Pyramids; and to crown the whole, had the honour of an interview with Mehemet Ali, Cleopatra, and Alexander the Great." Ten minutes sufficed to enable a friend of Dr. Abercrombie's to cross the Atlantic and spend a fortnight in America. Still more wonderful is another case cited by Abercrombie, where a gentleman dreamt that he had "taken the shilling" as a recruit in a marching regiment, that he deserted, was pursued, captured, tried by a tedious process of court-martial, condemned to be shot, and led forth for execution. The usual preparations were made. A gun was fired, and its report roused him from his troubled sleep, whereupon he found that a noise in the next room had not only awakened him, but had actually given rise to the whole dream. Such cases indicate that in the dreaming state thought courses through the brain with such lightning-like velocity that not a few critical persons have affected to believe that fancy and not fact is the parent of these observations. Yet, if De Quincey's veracity be impeachable, we cannot doubt the truthfulness of Dr. Macnish, who recounts his own experience; and if the evidence of Dr. Abercrombie's unnamed friends be but second-hand or hearsay testimony, surely we cannot disbelieve the following statement of such a shrewd, unimaginative, common-sense, observant, and eminently truthful man as the late Lord Holland. Sir Benjamin Brodie says that on one occasion when his lordship was much fatigued "while listening to a friend who was reading aloud, he fell asleep and had a dream, the particulars of which it would have occupied him a quarter of an hour or longer to express in writing. After he woke he found that he remembered the beginning of one sentence while he actually heard the latter part of the sentence immediately following it, so that probably the whole time during which he had slept did not occupy more than a few seconds."

The extent to which dreaming affects consciousness of identity is a matter of dispute. Many hold that a dreamer never loses the consciousness of personal or moral identity—in other words, that the dreamer never dreams he is somebody else or fancies he commits acts the shocking iniquity of which would make him shudder in his waking moments. This belief is flatly contradicted by others, with whose experience and observations those of the writer are certainly in accord. No man, it is said, ever dreamt he was a woman; and Sir William Lawrence once told Fanny Kemble that no woman ever dreamt she was younger than she really was. It may be admitted that no case is known where a dreamer has lost the consciousness of sexual identity; that, however, is surely a very different thing from losing the idea of personal identity, and it is not at all inconsistent with the fact that men have dreamt they were other men, and women that they were other women. Sir William Lawrence's observations must be regarded as mere *badinage*, for nothing is commoner than for women as well as men to dream that they are children again; or for both men and women, when they

dream that they are other people, to dream that those whose identity they assume are either older or younger than themselves. As regards his own personality, we may say the dreamer may be either a passive spectator in the scene which is painted by his dream-fancy, or he may be an actor personally in it, or he may dream that though he is an actor in the visionary drama, yet he is not himself, but somebody else altogether. Stranger still, the dreamer may have a vague consciousness that he is dreaming, and construct a dream within a dream. It would be but an imperfect account of the phenomena of dreaming that made no reference to those visions of prophecy and reminiscence which bulk so largely in the literature of the subject. They, however, throw little light on the true theory of dreams, because beyond the oddity of the results there is nothing extraordinary in the fact that during sleep, whilst all the other faculties are torpid, one—that of memory—should be unusually active, or, that out of the thousands of dream-combinations some few by mere coincidence tally with the sequence of actual facts and events, past, present, or future. It seems natural enough that the man whose whole soul is wrapped up in money-getting should now and then dream of lucky ventures and speculative enterprises "of great pith and moment." The love-sick may naturally be expected to dream of the objects of their devotion, and the wronged of the wrong-doer on whom they hope to wreak their revenge.

It is much more interesting to glance at another matter regarding which there has been much discussion—to wit, the alleged continuity of the dreaming and waking state. It was Emmanuel Kant who said that when we ceased to dream we ceased to live; and from the time of Descartes to that of the late Sir William Hamilton, it has been a favourite doctrine of metaphysicians that the human mind, as a matter of fact, never sleeps; that during sleep it is always working; that it is ever dreaming, though it is not always capable of recalling its dreams when roused from slumber. In so far as this doctrine is matter of argument, it must be admitted that the Cartesians fairly hold their own with their sceptical critics, who, like Locke, are apt to deride the notion that a sleeping man can think that which when awake and in full command of his faculties he cannot remember. It is just to remind the followers of Locke that people who during sleep present all the appearance of dreaming—tossing, laughing, and even talking—are, as a matter of fact, unable when they awake to recall their dreams or reproduce their thoughts. On the other hand, it is simply impossible to prove that the sleeper is always thinking and dreaming. It is nonsense to say that life depends on cerebral activity, for we know that in the prolonged trance of fasting women there is not a trace of mental action to be seen; and yet life has not fled from the sleeper's body in such cases any more than it has vanished when animals hibernate. Again, the safe and positive evidence of experiment is opposed to the Cartesian doctrine. Just as it has been possible to subject the brain of the sleeper to actual observation, so is it possible to see what changes occur in it when dream-fancies sweep and surge over the plain of suspended consciousness. When a portion of the skull has been removed by the well-known operation of trepanning, the surgeon can see what takes place in the brain-substance that he has been obliged to expose. In such a case, when sleep is dreamless, the brain is pale, shrunken, and bloodless; but when disturbed by dreams, the organ swells in volume, protrudes from the opening in the skull, and its pallor disappears as it is overspread by a rosy blush. From these well-attested facts what may we infer? It is clear that whenever the sleeper dreams, his brain, from being shrunken and bloodless, becomes enlarged, and its vessels charged with blood. This same increase of size and congestion are always noticeable when there are signs of dreaming present, no matter whether the sleeper recollects or does not recollect the dream. In a word, without saying that the enlargement and congestion of the brain are the causes of dreaming, we may say that these changes are the invariable external signs of brain-dreaming. But the brain of the sleeper is not always congested or enlarged—as it would be if dreams were always coursing through it—and this, we take it, is about as conclusive an argument against the Cartesian and Hamiltonian theories as can well be demanded. We are forced then to conclude that the bloodless state of the slumbering brain is an indication of dreamless sleep, and that there is no absolute continuity between the condition of conscious thinking and that in which dreams hover over the mind like fleeting cloud-shadows on the ridge of a softly-rounded chalk-down. We may therefore sleep so soundly as to cease thinking without ceasing to live. We are not all Manfreds, doomed to wander restlessly in gloomy Gothic corridors soliloquising on the horrors of a haunted couch, and exclaiming

> "My slumbers, if I slumber, are not sleep,
> But a continuance of enduring thought,
> Which then I can resist not. In my heart
> There is a vigil; and these eyes
> But close to look within."

What has now been said with regard to the relation of dreaming to sleep helps us by a natural step to a correct theory of dreams. Observation of facts is certainly in favour of the physiological as opposed to the metaphysical theory of dreaming. It is not possible to assert that dreams are the outcome of certain mental faculties wholly independent of bodily functions, and not affected by the sleep which suspends the activity of these functions. The observations made on the brains of patients who have been trepanned indicate that dreaming is not independent of bodily function, and that, if it be not absolutely dependent on it, it is at least never dissevered from it. There seems to be between dreaming, and the condition of the blood-circulation in the brain during sleep, an indissoluble connection. The phenomena of mental or spiritual life may not be effects or offshoots of mere physical or bodily acts or functions. But the two are so linked together that the bodily functions, at least, appear to furnish the conditions that make the mental phenomena possible. It would be a waste of words to argue that the congestion of the sleeper's brain causes the dream, or that the dream causes the congestion of the sleeper's brain. What we may say is that the two facts are so linked that the brain-action appears to set forth the essential conditions under which dreaming is possible. What are we to say of the origin of dreams? Where and how are their materials elaborated? What determines the order of their combination, and how are we to account for the extraordinary vividness of dream-fancies? Mr. Sully, one of the most thoughtful of modern writers on dreams, very satisfactorily divides "the exciting causes of dream-images" into (1) peripheral, and (2) central stimulations. In other words, sensations which arise in the surface or superficial parts of the body, and exciting vibrations or movements that take place in the central portions of the nervous system, furnish the mind or brain with dream-materials. A good illustration of a dream which derived its materials from a peripheral source of stimulation is that which Dr. Gregory records, in which, when he had a hot-water bottle applied to his feet, he dreamt he was walking on the scorching lava of Mount Etna. No doubt, as the pressure on and the temperature of the surface of the sleeper's body are constantly varying, the different sensations so occasioned afford an abundant variety of peripheral stimuli for dreams. The muscular movements of the body during sleep, the different positions of comfort and discomfort into which the body is thrown, doubtless help to give rise to the dreams of athleticism—dreams of which physical activity is the leading trait, and in which the sleeper has visions of marvellous feats of strength. In the same way variations in the condition of the different organs of the body—the stomach, heart, lungs, liver, teeth, and the like—supply the materials of many other dreams, such as those visions of luscious banquets that disturb the slumbers of the starveling, or visions of the bloodshed of battle which make miserable the restless nights of people about to suffer from hæmorrhage of the stomach or lungs. As to the central stimuli of dreams, it is not easy to describe them. That certain movements or actions in the core of the nervous system itself must excite dreams is more than probable, because perceptions that have been printed on the brain, or in the mind, one week, may produce as after-effects, and quite independently of external causes, all sorts of strange visions a month or two afterwards. Regarding the manner in which dream-images order themselves, it is extremely plain that in some dreams they do not order themselves regularly at all, whilst other dreams are marked by a most singular amount of coherence. The cause of disorder in dreams is easily understood. In such visions the materials are being poured in upon the brain from a great number of different sources, and by a great number of different stimuli, external and internal, at once. The regulating power of the will is in abeyance. The circulation in those brain-tracts, whose activity furnishes the condition of volitional action, is too feeble to enable the mind to exercise any control over the rapid and heterogeneous flux of dream-materials in which it is submerged, and the result is a vision deliriously incoherent.

But how are we to explain the occurrence of dreams that are not disorderly and chaotic? There is no doubt that all attempts hitherto made in this direction are, more or less, of a fantastic nature. Perhaps the utmost we can say is, that in some cases accident so orders it that no incoherent sequence of images is poured upon the mind by the external or internal stimuli of dreams; whilst in others, although the flow of images is chaotic, yet the mind has retained enough power to arrange them into, or impose upon them, rational form and symmetry. Let us assume, for example, that sleep is not deep enough to neutralise the action of that portion of the brain in which the physical

conditions of the faculty of association manifest themselves. Let us suppose that the nerve-centres which control the circulation of the blood in the brain, so far from shutting off the flow of blood from this tract of the organ, let it run pretty freely, what might we not reasonably expect to happen? The sleeper, when one dream-image was found in his mind, would, of course, in virtue of the active associative faculty, be able to link it to a series of others, with which, or with the like of which, in waking mood, he would be in the habit of seeing it combined. Thus would a series of dream-fancies be evolved which would be neither incoherent in their mutual relations, nor wildly disarranged in their sequence and procession. Mr. Sully has ingeniously suggested that the coherence of dreams may also be accounted for by the activity of the mind "under the influence not of the will, but of certain vague emotional impulses." Of these, he considers the chief one the "feeling for unity, and the instinct of emotional harmony." It is, however, hard to understand how this theory can be described save as a restatement in new phraseology of the old doctrine that sometimes in sleep and in dreaming the mind's power of voluntary control over its processes or its ideas is not altogether in abeyance. When the dreamer endeavours by a selective action to fix in the flow of dream-fancies only those that are capable of coherently combining with each other, it is difficult to understand how he is able to give effect to his "feeling for unity," without some more or less vigorous act of volition.

The desire for emotional harmony may very likely force the dreamer in many cases to order his dream in accordance with it. But then again, it is not easy to believe that in such a case the coherence of the vision is not after all due to a pretty distinct act of volition. Otherwise, how is the sleeper able to reject all ideas that are in conflict with the prevailing tone of emotion—be it pleasurable or painful—which the presentment of the first dream-image in the series has raised in the mind? With regard to the strange and intense vividness of dream-images, it is certainly remarkable that they should seem even more solidly real than the impressions made on us by the waking state. M. Taine, and other writers who have theorised on this matter, do little more than reproduce the old view of Hartley, which is full of good sense. He pointed out that in sleep we are withdrawn to a great extent from the influence of the external world, and there is no other reality than that of the dream present to oppose or interfere with the vividness of the ideas which crowd on our minds in dreamland. Experiment, however, points to another explanation, or, to speak more correctly, it puts the old one in a new light. The intensity of the stimuli which are the excitants of dreams bears no relation to the intensity of the impression they produce on a sleeper's mind. That this impression is always, or usually, monstrously exaggerated, is proved by M. Maury's experiments. He produces some external irritation or stimulus in a sleeper, and then wakens him at once, so that there is no time for the dream, which is thus provoked, to slip from memory. In this way he found that if the lips of the sleeper were gently tickled, he fancied in his dream that he was being tortured, and that pitch-plasters were being pasted on his face, and rudely torn off again; indeed, innumerable instances of a similar sort might be cited. From these it is inferred that during sleep the brain is unusually excitable, and that it accordingly exaggerates impressions conveyed to it from the external world. This physiological paradox helps us to understand why dream-images are even more vivid than those that are formed during our waking movements, and so far it serves a more useful purpose than most paradoxes.

WHY THE SEA IS SALT.

By W. A. Lloyd,

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BEFORE me are two creatures—a gold-fish in a glass bowl of water, and a canary-bird in a wire cage of air. I do not select these because they afford examples of the manner in which strongly-marked variations of forms and colouring of animals are caused by domestication and inter-crossing, but because these two forms of life constitute a pair of yellow pets the most frequently to be seen in our homes. The bird-cage represents the most ordinary shape of a *vivarium*, which is a name for any receptacle for any living animal, and the fish-bowl is the most often seen thing which we term an

aquarium, or *aqua-vivarium*, if we wish to adopt Dr. Edwin Lankester's more precise term. Reverting to the bird and the fish, I have to explain that their two primary requisites are food and water. The *food*, which must be organic in its nature—that is to say, must be either animal or vegetable food, or both—is requisite to repair waste, which is always going on while life exists; and the *water* is equally needful to maintain the fluid part of the body, which in every creature forms the largest proportion of it. This fluid is always passing away in some form or other, and it is required to be as continually re-supplied, both to animals and plants. Consequently, its *universality* is extraordinary—as much so as its *indestructibility*. If we put into a strong and dry glass vessel, previously exhausted of its atmospheric air, one measure of oxygen and two of hydrogen, and by an interior electric spark set fire to these gases, they combine by explosion, and a flash of light is seen, while the interior of the vessel is covered with a fine dew, which is water, occupying only about $\frac{1}{800}$th part of the volume of the mixed gases. This proves that water is nothing else but these two gases chemically combined, and not mechanically mixed; and as the same water can be again separated into these gases, mechanically *mixed*, and not chemically *combined*, nothing more is needed to show that the composition of water is as I have named. As to its absolute universality, proofs are so abundant that it is very hard to select them. Here is one out of many examples. I hold before a fire, on a fork, a piece of bread, to convert it into "toast." The first thing seen is a momentary cloud of vapour rising from the bread. This is the *water* it contained, which the heat of the fire converted into steam (or, more properly, invisible steam partly condensed into visible water), and it is very different from the other cloud which in a few minutes following will rise from the bread when it begins to char or burn at its surface. Again, take so common a thing as a wooden lucifer match, weighing exactly 2·94 grains. Another one might have weighed a little more or less, but that is of no consequence for my purpose. I put this headless match in a small bottle of hard, thin, clear German glass (Fig. 1), which, with its stopper, both being clean, dry, and polished, inside and out, together weigh 130·99 grains. I insert the stopper, and I expose the match inside to the flame of a reading-lamp, holding it horizontally above the chimney, and passing it quickly to and fro, so as not to crack the glass, though it is prepared specially to withstand heat. After the lapse of thirty seconds, I perceive a narrow patch of cloudiness along the cool upper inside of the bottle, and on examining this strip with a magnifying-glass I find the strip of dimness to consist of an aggregation of minute drops of water, which the warmth has driven from the match, as the fire had driven it from the bread, and which, instead of escaping into the air, was confined in the bottle, and which I can now weigh. In doing so it is found, on quickly dropping out the match, and replacing the stopper, that the bottle now weighs 131·03 grains, being a gain of 0·04 grain, in consequence of the access of water clinging to its sides and evaporated from the match; while the match, on weighing it, is found to be 0·04 grains lighter—namely, 2·9 grains instead of 2·94 grains. Dry the bottle carefully again, and it will be seen that it has regained its normal weight. Now, take a long piece of paper the area of a halfpenny stamp, and cut minute portions off its corners till its weight is made precisely half a grain. Let this be placed in the bottle (Fig. 1), and heated as was the match, and in a few seconds we see a tiny cloud inside the glass. On removing the bit of paper and replacing the stopper, we find there is, on weighing, a gain of 0·01 grain to the bottle, and a loss of 0·01 to the paper. In a few hours, however, on leaving the bottle open, and the match and paper exposed, the bottle has lost weight, as the water has evaporated from it, and the match and paper have gained weight, having absorbed moisture from the air. But how do I know otherwise that moisture is in the air? Nothing seems less like it on this hot, blazing summer day on which I write, with the temperature at 85° Fahr. in the shade, all local disturbances tending to mark a higher or a lower heat being carefully eliminated, and the heat being 75° Fahr. even in my cool room. The white road before me seems baked with the intense blaze, while the nearly black asphalte foot-pavement is by it made so soft that passers' heels leave deep dents;

Fig. 1.—Bottle for conducting Experiments as to the Evaporation of Water. (*Actual Size.*)

and the leaves of trees, and herbage generally, everywhere, are thickly covered with greyish-white dust. Add to this, that the suburb of London where I live is remarkable for its want of water. We have neither river, nor brook, nor pond anywhere near us, and a tiny rain-supplied spring which wells up in a field opposite us is one of the wonders of our village. Yet, there is water everywhere, even in the parched air of this noon of a mid-summer day. This can be shown in an instant. I get an ounce or two of ice, and I break a portion of it in small bits, and put it inside the bottle (Fig. 1). See—in a moment the *outside* of the bottle is bedewed with moisture, a magnifying-glass revealing numerous minute and closely-packed beads of water, just the same as those beads which in a former experiment we saw *inside* the bottle. The water cannot, of course, have come through the glass of the bottle. It came from the air. That is to say, the cold inside the bottle was lower than the temperature outside it, and hence the moisture in the air in contact with the exterior of the glass was so reduced in its temperature, that it could no longer retain its invisible gaseous state, and it became condensed as visible water by the cold, as the fiend was made unwillingly visible by the touch of the spear of Milton's Ithuriel. After awhile, when the ice melts, and its resulting water has assumed the temperature of the surrounding air, the outside of the bottle becomes dry, matters being thus brought to a balance. Thus, water is everywhere contained in whatever can take it up.

Its absolute *indestructibility* is a great marvel. Not a drop of water out of the enormous quantity of that which is "in the heavens above, in the earth beneath, and in the waters under the earth," has ever been lost or destroyed in any way, nor can it be so lost. That which was in the great ocean last week or month—perhaps in the Antipodes, perhaps in the Atlantic, possibly below the surface of the calm and seldom disturbed and intensely salt Dead Sea of Palestine, may be now, to-day, bubbling up in the tiny spring I have named in our Lower Norwood field, on the other side of our railway. Next year it may possibly form part of the steam which is puffed from the funnel of the locomotive engine on that very railway. Or it may be employed as a means of washing into the river Thames the emanations of the millions of human and other animals which London contains, and in finally carrying them into the great recipient of them all—the ocean. Then afterwards, or before then, it may be drank by human or other creatures as clear water, or as the basis of any of the many beverages with which thirst is quenched. Or it may circulate through our bodies, or the bodies of animals, as the basis of blood, or through the circulatory systems of vegetation in the trees and herbage around us. But it is never destroyed, and never has its constituents changed in proportion, no matter how varied its form may be, as in ice, or actual water, or visible or invisible vapour, or mixed with any other substance whatever. It may come in contact with fire, and may thus become changed into its constituent gases; but it is again reformed—again,

Fig. 2.—Bottle for Testing the Bulk and Weight of Water. (*Actual Size.*)

and again, and again—endlessly. In Fig. 2 is shown the actual size of a small bottle used continually by the writer in his work. It is made so as to contain 500 grains' weight, which is a little more than one ounce, or two cubic inches, of the purest water obtainable. The weight of the bottle itself, dry and empty, is about 240 grains, though that is of no great consequence; but when this weight is counterpoised in an assay-balance, then it is found to be exact to the $\frac{1}{100}$th part of one grain, there being 7,000 grains to one pound. The bottle must be quite full inside, and quite dry outside, and the minute hole seen running along and through the stopper serves as a kind of safety aperture, enabling the bottle to be completely filled without bursting. This aperture serves also to allow me to show the largest amount of water I have found in a lucifer match

in an ordinary condition, and fit for use on a wet day—namely, $\frac{1}{10}$th of a grain, which happens to be by accident as much as the hole will contain, which is the $\frac{1}{5000}$th part of the contents of the bottle itself. One-tenth of the hole full of water, therefore, is what a halfpenny stamp without its gum usually contains of water. In other words, 5,000 lucifers, or 50,000 halfpenny stamps, may contain as much water as this bottle holds. When I allude to pure water, I write of what one very seldom sees—namely, a compound of oxygen and hydrogen, and nothing whatever else. If I take some of the water from the little cool bubbling spring over the way, and weigh the bottle full, I find it somewhat heavier than 500 grains. And if we take some from the turbid small hole into which it runs, at the bottom of the field, near the edges of which all the urchins of our village play, and into which they cast much filth, we find it still heavier, as it contains in solution, both seen and unseen, various matters besides water, all more heavy than it, and in the case of some of them adding to its weight without proportionably adding to its bulk. So we take some of this impure and heavy water, and place it in a glass retort, to the bulb of which heat is applied, letting it boil, or rather simmer, gently, when steam slowly emerges from the tube of the retort, and this is converted into water, which falls, drop by drop, into a suitable receiver. We then weigh this water, which has been condensed from steam, and find it very nearly pure, because of the small power which the impurities had in rising as vapour and passing off with the steam. If we distil the same water twice over, we shall find that the bottle shown (Fig. 2, full) weighs very nearly 500 grains, or a trifle over—say about the $\frac{1}{100}$th of a grain. As a matter of fact, however, the purest water the writer has ever been able to obtain at the third distillation was $\frac{2}{10}$ths of a grain in 10,000 grains, which is not quite a grain and a half in one gallon weighing 10 lb., or 140 bottles full as Fig. 2; and a single drop of such water evaporated on glass has always left a visible residual film.*

To make more strikingly apparent how bodies may have the same weights, but yet occupy very different spaces, I have here drawn a diagram (Fig. 3) showing five fluids and three solids with an accuracy which is as near as can be attained on so small a scale, but which, if not absolutely correct, is yet sufficiently so to express the relative densities of each substance :—

1. *Pure Water.*—For convenience, this is considered as 1, or 1,000, and is everywhere accepted

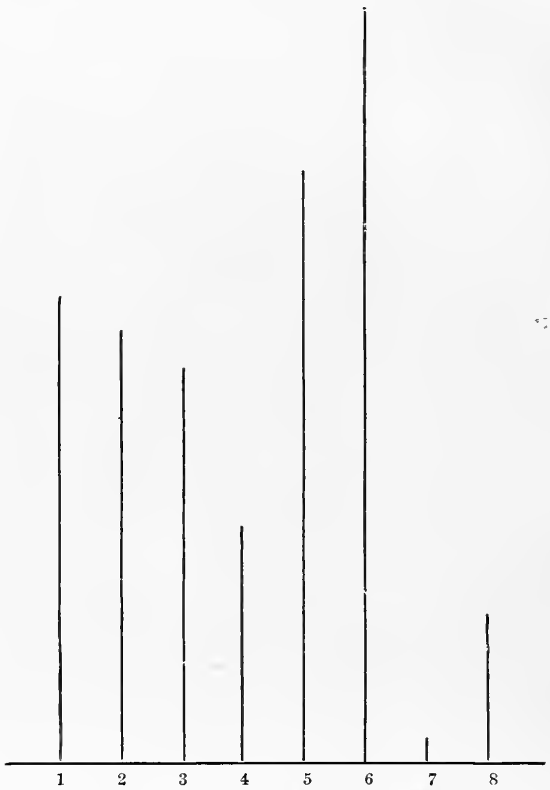

Fig. 3.—Showing relative Densities and Weights of Various Substances.

as the standard by which all other bodies are weighed and measured, both those which are lighter, and those which are heavier, than it.

2. *British Sea-Water.*—Specific gravity, 1020 to 1027.

3. *Dead Sea Water.*—Spec. grav., 1180 to 1200.

4. *Strong Sulphuric Acid.*—Specific gravity, 1800 to 2000 (the heaviest fluid known, not being a melted metal).

5. *Ether.*—Specific gravity, 0·720 to 0·800 (the lightest fluid known, not being a gas).

6. *Lithium.*—A metal: specific gravity, 0·593 (the lightest solid known). It will float even on No. 5. Such substances as cork and pith are not really solids. They owe their lightness to being much permeated with air, mechanically.

7. *Platinum.*—A metal: 21·055 to 22·069 (the heaviest substance known, except, perhaps, hammered iridium).

* Professor Geikie ("Physical Geography Primer," p. 88) is certainly in error in saying that spring water leaves no such film. Not merely does spring water, and that least impure natural water, hoar-frost, or frozen dew, leave a film, but even distilled water does so.

8. Mean density of the entire earth we live on, 5·662.

So we see clearly that water is a solvent of many things. Also that it can be evaporated, when it either passes off into the air visibly or invisibly, as steam does as it issues from the spout of a kettle; or the steam may be arrested and re-converted into water. Now, of the whole extent of our earth's surface, about thrice as much more of it is covered by water than is covered by land. And on some part of this watery surface of enormous extent, the hot sun is always shining, and ever causing vapour to rise from this water, both from seas, lakes, rivers, and wherever else in either solids or liquids, in which it occurs, just as we caused it to rise in vapour from wood, paper, and anything else containing it, in my bottle (Fig. 1), and as it is made to rise in a retort, and to be deposited again as water in each of those instances, by contact with something colder than that vapour. Watery vapour rises even from *ice*, at far below the freezing-point of 32° F. But, all, or nearly all, of the solids which the water may contain are left behind, and these do not rise up into the air. Therefore the sun may be regarded as an enormous pump of vast power, which every moment is lifting into the air millions of billions of tons' weight of water. It is very difficult, thus, to express in figures the amount of all the waters which we know to exist and flow everywhere. And our earth—the huge globe on which we live—is by its attraction always drawing down this water towards itself by the force of gravitation, or by that mysterious power which causes smaller bodies to be drawn towards larger ones; and what we call "weight" meaning the measure of the amount of that force. The earth is pulling down all things towards its centre, and the force which measures that pull is termed *ponderosity*, or *weight*, and the nearer the matter being pulled is to the earth's centre, the stronger is the force which pulls it. Thus, the bottle which contains 500 grains' weight of water at the earth's surface would contain nearly 14 times that weight in the same bulk if it were at the bottom of a hole 400 miles deep. In other words, at that distance from the earth's surface, water would weigh the same as the metal mercury weighs at its surface. Water, too, is constantly engaged in a mechanical denudation of whatever it runs over, the wearing-away power depending on the speed of its flow, or the strength of its striking force. This, therefore, is the process—the sun's warmth converts water into an aqueous vapour, which is lighter than atmospheric air, and which accordingly rises in that air and mingles so intimately with it. This is why the bottle (Fig. 2) is inscribed with the temperature of its correct weight—60° Fahr.—as, if the water it contains were higher than that, it would be lighter than 500 grains, and the fluid would occupy a larger space. The first thing, therefore, which water does on becoming warmed, is to increase in bulk, and this increase goes on till it becomes vapour. And when it is cooled it becomes smaller and smaller in bulk and heavier in proportion, until, just before it is cooled down to freezing-point, it again becomes lighter. Hence, ice floats in water, which is a wise provision, as, if it sank, and fresh increments of ice formed over what was submerged, the quantity of ice formed in winter would be too great for any summer's sun to melt it. It seems to me, therefore, that my little bottle (Fig. 1) is an excellent and original illustration, on a minute scale, of the operations of nature, as showing how heat causes water to rise invisibly, and then how cold causes it to be deposited and to fall down upon the earth again, as water, in the form of rain, snow, hail, dew, or sleet. We did not, in our small experiment with the match and piece of paper (Fig. 1), get enough water to fall, as we could have done by several repetitions of the trial, and therefore the slight dimness we obtained inside the bottle formed a further and apt illustration of clouds in the sky when they are masses of visible vapour not specifically heavy enough to fall.

I have already mentioned the solvent character of water, or its power of taking up and dissolving out, more or less, whatever is soluble in whatever it flows over, or runs through—this chemical result being aided, of course, by the mechanical erosion which accompanies its flow; and this summer I have been so fortunate as to procure samples of water from various distant places, showing this strikingly, and I have displayed these results in a tabulated form. There are five columns, of which A is the one giving the number of the twenty kinds or groups of water; B refers to their denominations; C presents the actual quantity of dissolved matter in grains and fractions of grains in the bottle (Fig. 2); D expresses the specific weight of the several waters in comparison with ideal pure water, which is always regarded as 1,000 (whether grains, pounds, tons, or what not); all other substances, solid or fluid, being calculated according to this universal standard. Thus, if Fig. 2 contains 500 grains' weight of pure water, it would contain about 900 grains' weight of strong sulphuric acid, which is the

heaviest non-metallic fluid known. Or a solid piece of the metal platinum, exactly fitting its interior, would weigh over 11,000 grains; while a similar piece of the metal aluminium would weigh only 1,250 grains. This specific lightness of aluminium is a fortunate thing for me, because in making out the following table, I have had to use weights so small that some can only be seen with a magnifying-glass, and if they were made of any other metal than aluminium I should hardly be able to see and handle them at all. I have to explain that in weighing these several waters, I have not, once for all, used a 1,000-grain bottle, because so great a weight as that would be nearly (with the counterpoise) three ounces in each pan, and that would be an injurious load for my very sensitive balance. Hence I double C to get D. E expresses in grains' weight the quantity of invisibly dissolved solids each kind of water contains in one gallon weighing 10lb. or 70,000 grains. Hence:—

"A pint of pure water
Weighs a pound and a quarter."

Hence, also, one pound weight is 7,000 grains. The quantities in E are got by deducting from C the number 500, that representing the pure water contained in Fig. 2, and then multiplying the residue by 140, as one gallon is exactly 140 times 500 grains. Column F shows the amount of absolutely pure water in one gallon of all waters found everywhere, and the actual weight of a gallon of any of the waters I have here set down can be seen by adding E and F together:—

A	B	C	D	E	F
1	Pure water (Monoxide of Hydrogen)	500·	1000·	—	70000·
2	Distilled water (third evaporation)	500·01	1000·02	1·4	,,
3	Melted hoar-frost (frozen dew)	500·02	1000·04	2·8	,,
4	Loch Katrine water (Scotland)	500·03	1000·06	4·2	,,
5	River Alwyn ,, (N. Wales)	500·09	1000·18	12·6	,,
6	Various well-waters in and around London	500·14	1000·28	19·6	,,
7	Thames water—mixed London samples	500·17	1000·34	23·8	,,
8	Seine water—mixed Paris do.	500·15	1000·3	21·	,,
9	Jordan ,, ,, samples (Feeders of 19 and 20.)	500·05	1000·1	7·	,,
10	Ain Wadi Zerka (Feeders of 19 and 20.)	500·09	1000·18	12·6	,,
11	Ain Jerabah (Feeders of 19 and 20.)	500·08	1000·16	11·2	,,
12	Baltic Sea water—weakest	502·95	1005·9	413·3	,,
13	,, ,, medium	504·19	1008·38	586·6	,,
14	,, ,, strongest	505·63	1011·26	788·2	,,
15	British ,, weakest	510·25	1020·5	1435·	,,
16	,, ,, strongest	513·88	1027·76	1943·2	,,
17	Mediterranean Sea water weakest	512·61	1025·22	1765·4	,,
18	Mediterranean Sea water strongest	516·43	1032·86	2300·2	,,
19	Dead Sea water—weakest	528·16	1056·32	3932·4	,,
20 *	,, ,, strongest	613·28	1226·56	15859·2	,,

* Mr. Wanklyn gives the specific gravity of the Atlantic Ocean—what part is not stated—so high as 1088·, but there is probably an error here.

I have never been able to get as much as 500 grains' weight of No. 1, and even with the expensive apparatus necessary to do so, I could not handle and weigh it in any manner not implying contact with air, so that it may remain pure. Absolutely pure water must be prepared in a vacuum, and it must never have had any contact whatever with air of any kind. Such water would be instantly fatal to any animal, as a fish, breathing it, simply because it contains no oxygen in solution which the animal can use to aërate its blood in its gills. It contains only oxygen in combination, and that the fish cannot separate and use. The result in No. 2 I should not have expected had I not obtained it by actual trial. I evaporated a gallon of distilled water twice, and the third time I allowed the water thus distilled to fall, drop by drop, into a small polished platinum capsule kept hot by a Bünsen burner, and at the end of the process the capsule weighed 81·08 grains, compared to 79·68 grains at the commencement, when it was chemically clean, inside and out, showing a gain of 1·4 grains. It was also a very tedious thing to collect as much as 500 grains of No. 3, which is the purest water known in nature. No. 4 comes next. It is very pure, because it flows over granite, on which it has but small action. But even this water is sometimes less clear and pure than at other times, as in the *Times* of August 15, 1878, Dr. Mills reports that it then recently contained "muddy particles, with some flakes." No. 5 I have selected because it is from the little river by the side of which I used to mind cattle when a lad; and while sometimes there was never more water than would cover a cow half-way up her legs, in the precise spot to which I allude, yet sometimes, after heavy rain, this tiny stream would be converted into a mighty roaring brown torrent, carrying all before it, both soluble and insoluble. No. 6 explains itself, and of course its matters in solution are obtained by dissolving them out of the soil through which it flows. Nos. 7 and 8 are examples of waters taken when the Thames and Seine were at their least best and cleanest. Nos. 9, 10, and 11, are exceedingly interesting as being currents which feed 19 and 20. I was very fortunate in getting these five, as well as five other examples in my list, all in one week. The very low marine specific gravity of 12, 13, and 14, is caused by the salts of the Baltic Sea (which, indeed, is but a large estuary) being washed away from it by the great rivers running in and out of its north end, and which sweep out, so to speak, its saline parts. So too, with the Black, and

Caspian, and Aral Seas, all being only brackish. Nos. 15 and 16 are very variable in their salinity. It is scarcely possible to find two examples from the same spot on two successive days, or even hours, without marking some difference in weight in them, caused by the influx of fresh water and tidal movements. In several places, especially in marshy districts near the sea-side, as near the mouths of the Thames and Medway, I have often seen both marine and fresh-water animals living together in the same water, and I have so kept them in aquaria at a density of only 1005· to 1012·. Nos. 17 and 18 are remarkable. The Mediterranean Sea is, as its name implies, a land-inclosed sea; almost so, that is, but having a small means of connection with other seas at the Straits of Gibraltar. This accounts for its high density, because its evaporation is great on account of the considerable heat of its climate and its inability to become more diluted by mixing with other seas. Nos. 19 and 20 are yet more remarkable. The Dead Sea of Palestine—so called partly from the sluggishness of its water, it being so heavy that wind can get but small hold of it—has its level 1,200 feet below the level of the Mediterranean, and therefore it has no outlet and no known exchange of water with any other sea. Then it is exposed to a burning sun, and its evaporation is correspondingly large. Added to this, the feeders of this sea contain much salt or substances in solution. No. 9, for example, has in it between three and four times as much as Nos. 3 and 4 have, while 10 and 11, also flowing into 19 and 20, have still more. Therefore, all circumstances combine to cause this very remarkable sea to be intensely salt and acrid. Precisely the same causes, acting in exactly the same manner, are the reasons why other very salt masses of water in nature are so. There is the Great Salt Lake at Utah, for example, which is salt to the point of saturation, when it *cannot* dissolve anything more, as the Dead Sea appears incapable of doing. It would be curious to know whether No. 19, representing the Dead Sea, where the water is much diluted by the entering Jordan, contains fish and other animals, such as live in other seas containing as much as or less dissolved solids than it does. Experiment may help in such a matter, and accordingly I have prepared some Dead Sea water—that is, I have compounded it according to analysis, and have arranged a small aquarium with it, and I await results for publication. Up to now, I have never been able to mix any fresh water with any sea water, in any proportions, giving densities varying, in twenty experiments, from 1003· to 1200·, without obtaining results both as to animal and vegetable characteristics, which demonstrate that the characters of the creatures and the plants largely depend on the amount of solids which the various admixtures contain. We see this in oceans, and rivers, and streams, as we see it in aquaria, large or small. Hence, to my mind, all books which divide their subject of aquaria into fresh-water aquaria and marine aquaria, seem unphilosophical, because one gradually merges into the other, in addition to both being governed by the same general physical and chemical laws.

Yet, if we look at each end of the whole great series of chains of fresh and sea waters on the face of the globe, and do not so much regard the more central connecting-links of the chain, we see that the general characters, of the animals especially, are largely influenced by the greater or less amount of dissolved solids in the water. Regarding only our British seas, for example, we have but one crustacean of any considerable size (*Astacus* or crayfish) in fresh water—and it is not very common, certainly not very large, and certainly local—to represent the vast number of great lobsters and crabs, &c., in the sea. This is what might have been expected from the difference in the water, as containing or not the materials for building the great and thick, heavy shells possessed by such creatures. Nor do we find in fresh water any shell-fish (mollusks) with such heavy and strong shells as oysters, and others, both bivalves and univalves, inhabiting sea-water. Those in fresh water are thin, light, and horny. In fresh water also there is an entire absence of the group of animals termed *Echinodermata* (sea-urchins, star-fishes, &c.), many of which secrete hard cases.

Thus we see that the saltness of the sea has been caused by the washings-out of the land, and chiefly by the disintegrated and always disintegrating salts of the rocks of the land. Not only are they constantly being worn away by mechanical abrasion against each other, and by the passing over them of forcible currents, but cold and heat greatly assist in their breaking up, and in having dissolved out of them as much as can be removed. I have mentioned that when water freezes, it expands and becomes lighter in a state of ice than when in the condition of water. This is of great value in making the sea salt. Supposing a porous stone containing much soluble matter gets saturated with water; if that water is frozen in the pores of the stone, the

expansion of the water in becoming converted into ice rends it asunder with enormous force, into small fragments, thus very greatly exposing its dissolving surfaces to the action of the water, and thereby hastening its solution. We see this action constantly in our houses in winter, by the bursting of pipes by frost. Earth, too, when moistened by falling rain, and then freezing, expands that soil, and makes it more porous and less compact, and so quickens the dissolving power of future rainfalls to remove from it all it can on its way to the sea, and there to deposit finally whatever it has gained. Even our little village spring is aiding in this work of conveying solubles to the ocean, as it has gathered matter even during its short travel underground from the top of the hill beyond, of which it is the visible drain. Then it sinks into the earth over a wide space, and when it again re-appears it will be found with yet more solubles in it. And when frost is not breaking up stones in winter, heat is doing so, in a less degree, in summer. Before me is a large porous stone, which in 1870 was wrought smooth by a mason. Ever since, sea-water has been allowed to enter it in such manner that it evaporates at its surface and leaves it dry. And the crystallisation of evaporation has acted in the same manner as the crystallisation of freezing, for the block of stone is at its surface deeply honey-combed and eroded, and is crumbling to powder, it having lost 25 per cent. of its weight in only eight years.

And so the world goes on. At the beginning of it—when it "was without form, and void, and darkness was upon the face of the deep"—that deep could not have been salt water, nor yet fluid water at all, though it was primarily the same water of 70,000 grains to the gallon that now exists. It was only when light was created, in the shape of the sun, the great source of all light, life, and heat, that water became converted into water, from ice. Then, on its assumption of fluidity, its present motion began, and it commenced by the power of the sun's heat to rise in the air as vapour to descend on the earth, and to gradually increase in saltness as it descended seawards. Without the sun and light there could have been no life either of plants or animals; but as soon as that light shone on the earth, motion, and life, and the saltness of the ocean, commenced simultaneously, and have been going on ever since.

If we had any means of ascertaining the amount of soluble matters contained in the "silver streak" of sea between the Continent of Europe and Dover when Cæsar crossed it, nearly two thousand years ago, to conquer England, we should find it contained less than when William the Norman crossed it for the same purpose a thousand years later, and

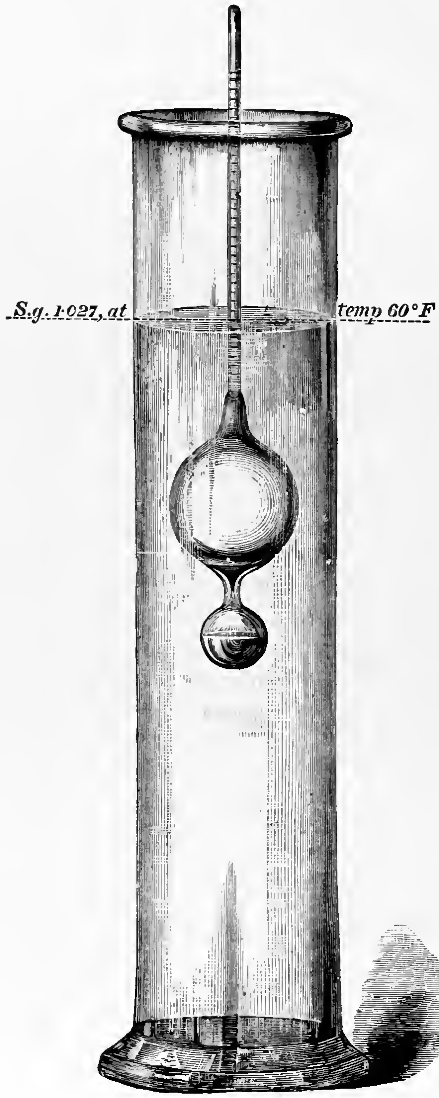

Fig. 4.—Hydrometer. (*One-third actual Size*).

that at the time of the Norman Conquest it was less salt than it is now; not much less, however, because a period of one or two thousand years is a very small space of time in the world's history. And so it progresses. Nothing stands still; nothing is repeated—

> "Nature brings not back the Mastodon,
> Nor we those times."

What was something yesterday is another thing to-day, and will be some other thing to-morrow.

Constant motion means continuous denudation, and that means incessant change, and that signifies never-ending evolution. Nothing is isolated, but everything is inter-dependent in such a wonderful manner that it is not possible for anything to happen to one thing unless it affects some other thing, no matter what their apparent remoteness may be.*

The mode I have described of ascertaining the density of sea and other water by weighing it, is, though very accurate, a process requiring much expenditure of time and money. Therefore a more usual, but rougher, mode of doing so, is by an hydrometer. One is shown in Fig. 4; it consists of two hollow glass balls united by a short neck. The lower and smaller ball is loaded with mercury, so that the stem surmounting the larger and upper one shall sink to a certain point marked on it. Then, on the water in the glass jar in which the instrument is floated being made more or less dense, or increasingly or decreasingly salt, the stem will be immersed or not in a certain proportion marked in degrees upon it. The regulation or degree of salinity is thus marked by the amount of the displacement of water made by the stem. The hydrometer here shown is made to show densities from 1·020 to 1·030 at 60° Fahr.

Another and cheaper mode of showing density of sea-water in aquaria is shown in Fig. 5, which is an engraving, full size, of the instrument I have used for many years. It is called a Specific Gravity Bubble or Bead, and consists of a small hollow glass ball, having a solid terminal shank, so arranged that the mass of glass and the air it contains shall be precisely equal in weight and volume to a mass of fluid which it displaces. It is extremely sensitive, almost too much so in unaccustomed hands, because the amount of force which causes it to sink to the bottom, or remain floating at the surface, of such a mass of water as is here represented, is extremely small, amounting probably to not more, if it could be measured, than the millionth of a grain weight for each inch of movement. The one represented is shown halfway down the water, there remaining stationary. The extreme delicacy of this little and cheap contrivance is such, that in the one shown, the increase of density caused by the height of so short a column of fluid as two inches, hinders the ball from sinking, while the lesser density of the upper half of the column, caused by the absence of pressure, hinders it from rising. In using it, the water should be corked in the tube for some hours before trial, that air-bubbles may escape, and that evaporation may be hindered. I have used this instrument as a means of illustrating quickly how the sea has become salt by evaporation, and I find the ball rises even after the most careful attention to temperature, when evaporation is compensated for by the addition of the purest water I can prepare, which, however, is never pure, and hence a small amount of solids gets introduced. I have also used it to show the minute increase of temperature which takes place in the motion of water. The drawback to such a bulb is that it can be regulated for one degree of density only; in the present one, this is 1·030 at 60° Fahrenheit exactly. The smallest difference of temperature affects it in a very marked manner, as no ordinary thermometer will indicate. The one shown weighs

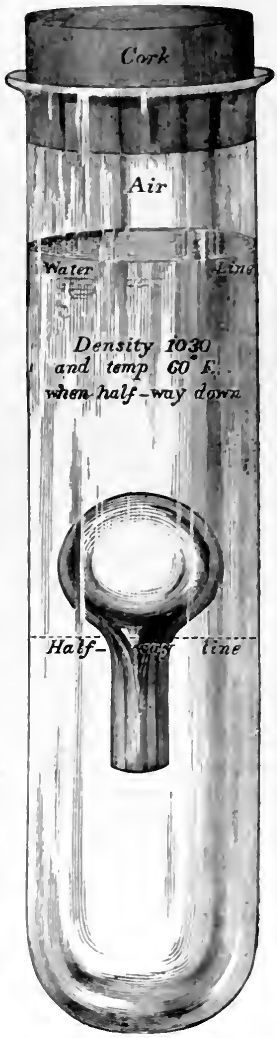

Fig. 5.—Specific Gravity Bubble in Tube. (*Actual Size.*)

* The late Professor Forchammer, of Copenhagen, was one of our greatest authorities on oceanic chemistry. In accounting for the fact that while the chief component of sea-salts is chloride of sodium, the main ingredient of river-water is carbonate of lime, yet he still accounts for the salts in the ocean being the gradual accumulations of those brought into it from rivers, by thus summing up:—"The quantity of the different elements in sea-water is not proportionate to the quantity of elements which river-water pours into the sea, but inversely to the facility with which the elements in sea-water are made insoluble by glacial-chemical, or organo-chemical actions in the sea; and we may infer that the chemical composition of the water of the ocean in great part is owing to the influence general and organo-chemical decomposition has upon it, whatever may have been the composition of the primitive ocean." Forchammer discussed this subject at the 1844 meeting of the British Association, and he and others have shown how molluscs, corals, hydrozoa (sea-firs), echinodermata (star-fishes, sea-slugs, and sea-urchins), and other carbonate of lime secreting animals deprive sea-water of carbonate of lime, and decompose sulphate of lime. Silica, abundant in river-water, is taken up by sponges, diatoms, &c., hence it is scanty in sea-water.

92·35 grains, and therefore the mass of water the space of which it occupies, weighs also 92·35 grains, while the dimensions of each must of course be precisely equal. The same law would govern, whatever the size and weight may be. Galileo is said to have made the first such density-ball of a mass of wax, into which he pressed morsels of metal till the right weight was obtained.

THE ANATOMY OF A LOBSTER.

By Dr. Andrew Wilson, F.R.P.S.

It is one of the most important features of natural science that a large proportion of the objects with which it professes to make us acquainted may be obtained from the surroundings of ordinary life. The botanist, for example, is everywhere surrounded by the objects of his study. "The meanest weed that blows" may present to his mind problems of the deepest import, and may serve to convey truths of nature of the most valuable kind. The despised worm or caterpillar, and the, in popular language, "nasty" frog or toad, serve, in turn, to teach the zoologist very many important facts concerning animal life at large, and demonstrate anew the saying that science has power to raise new worlds for thought from the objects that lie around our footsteps in such unheeded profusion. A very common animal has, in the present instance, been selected as the subject of a few lessons on the structure of the group "Crustacea." The common lobster is, perhaps, as familiar a denizen of the sea around our coasts, as exists. It is a being equally familiar to us in the fishmonger's shop, and, perhaps, most familiar to the generality of civilised mankind in the particular aspect which causes it to figure as an important element in "salads" and like culinary combinations. But if the animal may thus be shown to minister to the luxury and maintenance of man's body, its history is no less surely fraught with nutriment to the mind zoologically inclined. And even to persons of by no means pronounced natural history tastes, there may be much in the philosophy of a lobster to edify and instruct. In the search for such elements of edification we may, therefore, begin a brief study of this familiar animal.

That there are various kinds of lobsters is a fact which a glance at a fishmonger's window serves amply to substantiate. There is thus the common lobster to begin with—the *Homarus vulgaris* of the zoologist (Fig. 2). A second species, common enough in London, is the spiny lobster or sea cray-fish (*Palinurus vulgaris*), differing from the common lobster in the brownish-red colour, in the rough and spiny nature of the shell, in its usually larger size, and zoologically, in several important structural features, which need not be specially alluded to at present (Fig. 8). The common lobster being, however, the more accessible animal of the two, we shall select it as our type, although it may be remarked that much of our description of the lobster will apply to the sea cray-fish also—the two animals being related very much as first cousins are amongst ourselves. A live lobster is, comparatively speaking, an active animal. He may be seen to crawl somewhat majestically over the rock-work of his tank in an aquarium, and possesses the singular habit, when irritated in any way—and occasionally as a natural mode of exercise—of suddenly careering backwards in the water, by sharp contraction of the broad tail-fin he possesses. Viewed at rest, the long feelers wave backwards and forwards in the water, and certain of the mouth organs—of which the lobster possesses a formidable array—are seen to keep up a constant movement, which, we shall afterwards note, is intended to renew the water required for the "gills" in the act of breathing.

Suppose that we examine now the outward features of the lobster. The animal is encased, *cap-à-pie*, in a shelly armour, the shell being merely the skin hardened by the growth therein of lime. Curiously enough, the animal, along with its near neighbour the crab, periodically contrives to get rid of this armour, and slips out of the shell as deftly as a mediæval knight laid aside his accoutrements. For a time the skin remains soft and unprotected; the animal, from motives of self-interest, retiring into the obscurity of private life, until such time as the blood-vessels of the skin shall have brought their quota of limy matter, from which the skin will again construct a new suit of shell-armour. The occurrence of this process of "moulting" in the lobster becomes additionally interesting when we learn its physiological utility. The marked growth of

the animal may be said to be effected at the periods when the shell is shed and renewed. The increase of a body encased in an unyielding armour is simply impossible; hence the laws of periodical growth provide for the moulting of the shell, and for the formation of a new armour adapted to the enlargement of the body. It is an interesting fact, that in conformity with the law that growth is greatest in youth, we find the lobster to cast its shell more frequently in its early youth than in its later years. Thus, during its first and second years of life, the lobster sheds its armour six times, the third year four times, and only thrice in the fourth year (Fig. 1).

As everybody knows, when the animal is boiled the dark blue and mottled colour of the shell gives place to a bright red, a hue which more than one non-zoological artist has unwittingly reproduced on canvas as the natural tint of the lobster. The alteration of colour in the boiled shell is due to chemical changes, the exact nature of which need not be discussed here.*

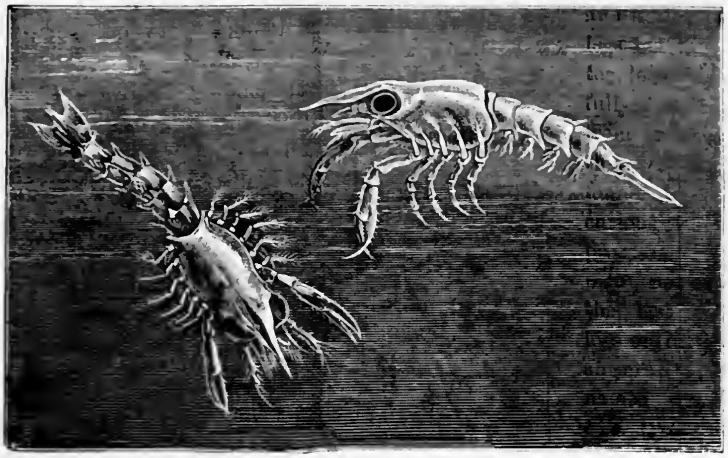

Fig. 1.—Young Lobsters at the Period of their Third Moult. (*Six Times Natural Size.*)

The lobster's body to ordinary observation appears to consist of a solid "head" and a jointed "tail." The question of "heads or tails" in the present instance requires, however, a little discussion for its satisfactory solution. The lobster must possess a "body," and it may be shown that the so-called "head" includes both head and chest, so that we find the animal to resemble an insect somewhat, in that it possesses a *head, chest*, and *abdomen*—the latter being the jointed "tail" of popular observation. It may be somewhat instructive at the present stage of our proceedings to institute a cursory comparison of the lobster and crab. These animals present very obvious points of resemblance even to a casual observer, and if examined in their young state would be found to present still closer resemblances. In the days of its infancy and youth the crab possesses a jointed tail (as described in the article "Some Animal Histories," Vol. I., pp. 77–8). Wherein consists the chief difference between the adults? The reply is, That the tail of the crab dwindles away by a process of natural decline, and becomes the little "purse" or appendage seen on the lower surface of the crab's body. Thus, practically, the crab is all head and chest, whilst the lobster exhibits a more normal state of matters, in that it possesses head, chest, and tail fully developed.

The appendages of our lobster's body are not merely numerous, but they are also paired. Every joint of the animal's body has a pair of appendages of one kind or another, but it is somewhat marvellous to find that despite the utter unlikeness of the appendages in some regions, they are modelled in an exactly similar plan in all. Such a lesson—namely, that of the essential likeness of the joints and appendages of the lobster's body—is one of the most important which we may learn from a dissection of the lobster. Take your lobster in hand, that you may see for yourself the facts to be noted, and count the joints of the abdomen, or, as we may call it, the "tail." Beginning first behind the "head," we can count at least *six* joints in the tail, the last joint differing from the others in possessing the broadened appendages which form the tail-fin. The statement that there are six joints in the head, and eight in the chest of the lobster, must be taken on trust, inasmuch as at present their disposition cannot be conveniently studied. But it may be well to remember that there are in all twenty joints in the animal's body; fourteen being comprised in the united head and chest, and six in the tail. Thus, to begin with, there could be little or no difficulty in referring the lobster to the great group of *Articulata* or jointed animals;

* Some one has called the lobsters the "cardinals of the sea;" but they are not cardinals until boiled. Yet in Raphael's famous picture of the miraculous draught of fishes, all the lobsters—albeit there are none in the Sea of Galilee—are painted red. The artist apparently only knew them in their culinary aspect.

and this *annulose* or ringed condition is seen to be equally well represented in such animals as centipedes, insects, spiders, &c. So that it would be a perfectly warrantable and correct inference to assume that these animals were related to the lobsters and crabs, at least in the general correspondence of their outward structure.

The most complicated series of objects in art or nature may be clearly understood if the common type or plan on which the objects have been constructed is appreciated. The joints of the lobster's body present us with such a series, and it behoves us firstly to gain a plain idea of the type on which they are built up. Such a type we may find most clearly and simply presented to us, in one—say the third—of the joints of the tail. Even when examined in its place, the structure of this joint may be satisfactorily made out, but a little care in separating it from its neighbours by carefully detaching it at either extremity will perhaps present it still more favourably for examination.

This third joint of the tail—counting from before backwards—consists of a *body* and *appendages.* The body and appendages form part of the very uniform set of joints that compose the tail; so that a knowledge of this one joint will serve as a guide to the structure of all the segments of the tail. Observe the arched upper surface of the joint you have separated. This is the *tergum* (Fig. 3, A *t*). Next look at the somewhat flattened lower piece. This is called the *sternum* (*s*), because it exists, so to speak, in the place of the breastbone of higher animals. Then, lastly, observe the sides of the joint, which are mere continuations downwards of the tergum, and serve when the joints are placed together to form the side walls of the tail. These side pieces form the *pleura* (*pl*) of the joint, and possess smooth surfaces in front for easy movement with the pleura. So much for the "body" of the joint.

The *appendages* are seen to be paired, and one appendage exactly resembles the other. First of all, look at the single joint, or piece of the appendage (*pt*), which springs from the body. This is called the *protopodite.* Attached to this protopodite are two other pieces. One of these, the outer, is called the *exopodite* (*ex*), and the other (the

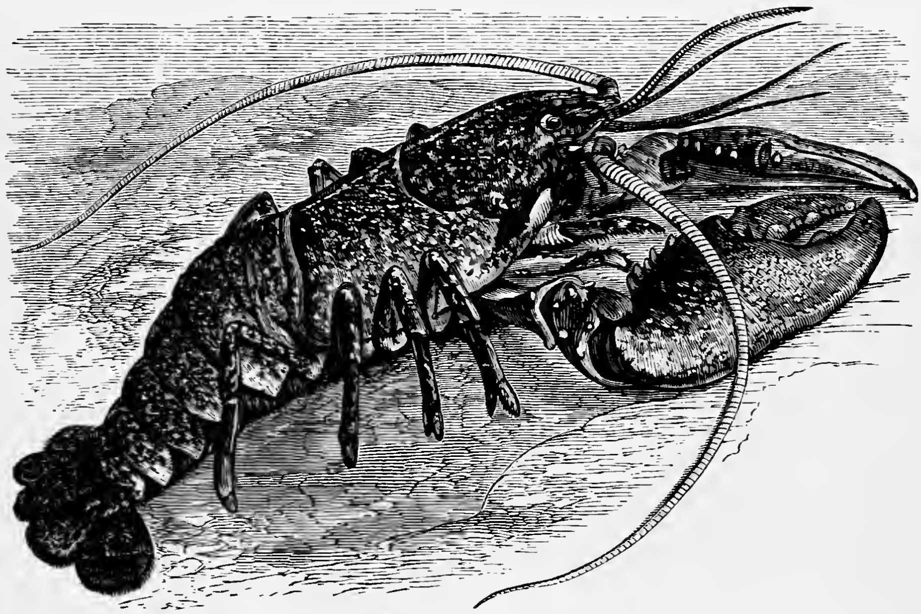

Fig. 2.—The Common Lobster (*Homarus vulgaris*).

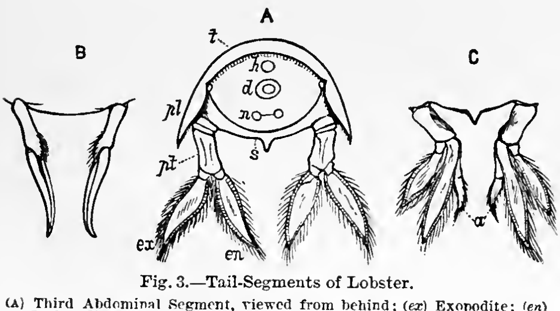

Fig. 3.—Tail-Segments of Lobster.

(A) Third Abdominal Segment, viewed from behind; (*ex*) Exopodite; (*en*) Endopodite; (*pt*) Protopodites, (*pl*) Pleura; (*s*) Sternum; (*t*) Tergum; (*h*) Indicates Situation of Heart; (*d*) of Digestive Organs; (*n*) of Nervous System; (B) Horny Appendages of first Abdominal Segment of the Male; (C) Appendage of Second Abdominal Segment, showing the little Processes (*a*) carried on the Endopodite.

inner one) the *endopodite* (*en*). The two appendages of each joint (each made up of *protopodite, endopodite*, and *exopodite*) are popularly named *swimmerets* (Fig. 3). They do not assist the animal much, or at all, in swimming, the chief use of these appendages being seen in the case of the female lobsters, in which they carry and support the great masses of eggs, when the animals are "in berry," as the fishermen say by way of denoting the breeding-season.

Now, begin the comparison of the other joints with the typical "joint" you have just examined. Begin with the sixth or last joint of the tail (Fig. 4, No. 6). At first sight this joint seems to be very different from the third. But after a little examination of this terminal joint you readily discover that its appendages (*protopodite, endopodite* and *exopodite*) are merely broadened out to form the tail-fin; the centre-piece of this fin being formed by the *telson* (*t*), a little flattened body, resembling a joint without appendages, but regarded most correctly as being merely an outgrowth of the upper part of the sixth joint. The telson is not a joint, but corresponds in nature to the *rostrum*, or "beak" (*r*) seen protruding in front of the lobster's head. Proceeding forwards, we find the fifth and fourth joints of the tail to resemble the third in all essential features. The second joint also resembles the third, save in that its endopodites possess each a little additional process (Fig. 3, C *a*). The appendages of the first joint of the tail of the male lobster are horny, spoon-like processes (Fig. 3 B; whilst in the female the appendages of the first joint are simple, flexible, and undivided. The result of our examination of the lobster's tail has thus tended to show us, firstly, that its tail consists of six joints, with a terminal appendage called the telson, which forms the centre of the tail-fin. Secondly, that the joints, despite a few modifications in their appendages, are essentially similar in form and structure. This is another way of saying that the joints of the lobster's tail are *homologous*.*

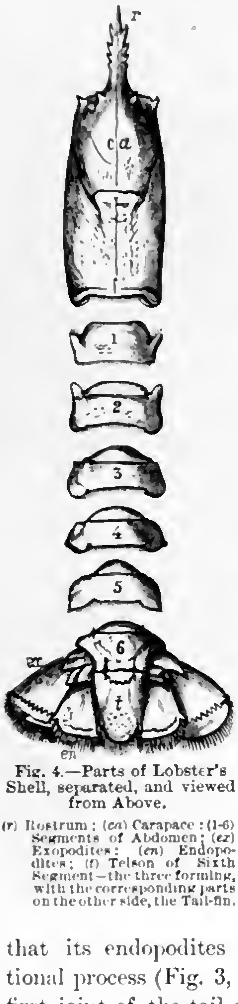

Fig. 4.—Parts of Lobster's Shell, separated, and viewed from Above.

(*r*) Rostrum; (*ca*) Carapace; (1-6) Segments of Abdomen; (*ex*) Exopodites; (*en*) Endopodites; (*t*) Telson of Sixth Segment—the three forming, with the corresponding parts on the other side, the Tail-fin.

But what may be said regarding the joints of which the fore part of the lobster's body—head and chest—is composed? There would be some difficulty in demonstrating the fact of the correspondence of these front segments with the tail, owing to the closely united nature of these head and chest joints. But, laying aside the difficulties which would beset the examination and dissection of the segments themselves, one way remains whereby the correspondence of these front joints with the tail-segments may be shown. This method is that of comparing the *appendages* of these head and chest joints with those of the type-pattern seen in the tail. If the foremost joints have been "made to order," so to speak, on one plan already seen in the tail, we should be able to trace some degree of likeness in the free appendages, even although the joints are massed together.

Beginning our examination at the back of the chest, for the reason that we shall be the better able to detect variations in the appendages as we go forwards, we firstly note that the sides of the one great shield (or *carapace*, Fig. 4, *c a*) which covers the head and chest, are formed simply of the united *pleura* (or side-pieces) of the different segments which comprise it. On the top of the carapace and about midway in its length, we see a prominent cross-groove. This groove marks the line of juncture between the lobster's head and its chest.

We have now to examine the appendages of the chest from behind forwards, and we have to account for eight pairs, seeing that there are eight joints at the chest. The appendages should be separated, pair by pair, from the dead lobster, and laid on a sheet of white paper in their due order to facilitate comparison. The first pair of appendages (those of the last joint of the chest, or fourteenth joint of the body) appear as a pair of walking-limbs (Fig. 5, M). The leg is formed simply of a long *endopodite*, its first joint or base being the *protopodite;* the exopodite, which you expected to find (remembering the type-joint of the tail), having disappeared. The question, "How is this knowledge arrived at?" may naturally enough rise to the lips of the student, who is not entitled to take such a statement on trust. The answer to the query bears, that where the correspondence of a series of organs in an animal is not apparent (through the modification of certain parts) in the full-grown state, the likeness may be traced

* See "The Cousinship of Animals," Vol. I., pp. 328-337.

in the young condition. What was the state of this last pair of legs in the young lobster? Each limb consisted, like the appendages of the tail, of a protopodite, exopodite, and endopodite. But the process of modification soon set in. The "endopodite" remained to constitute the "leg;" the "protopodite" formed its first joint, whilst the useless "exopodite" disappeared. The same may be said of the history of the thirteenth, twelfth, eleventh, and tenth pair of legs. If these latter legs be carefully dissected out from the body, they will each be found to bear a curious leaf-like process (Fig. 5, L *ep*), not seen in the last pair of legs or in the tail segments, and named the *epipodite*. Whilst certain of the gills (*g*), to be afterwards described, may be seen to be attached to the bases of the first three pairs of walking-legs, the use of the epipodites being to extend upwards, so as to separate the gills from one another.

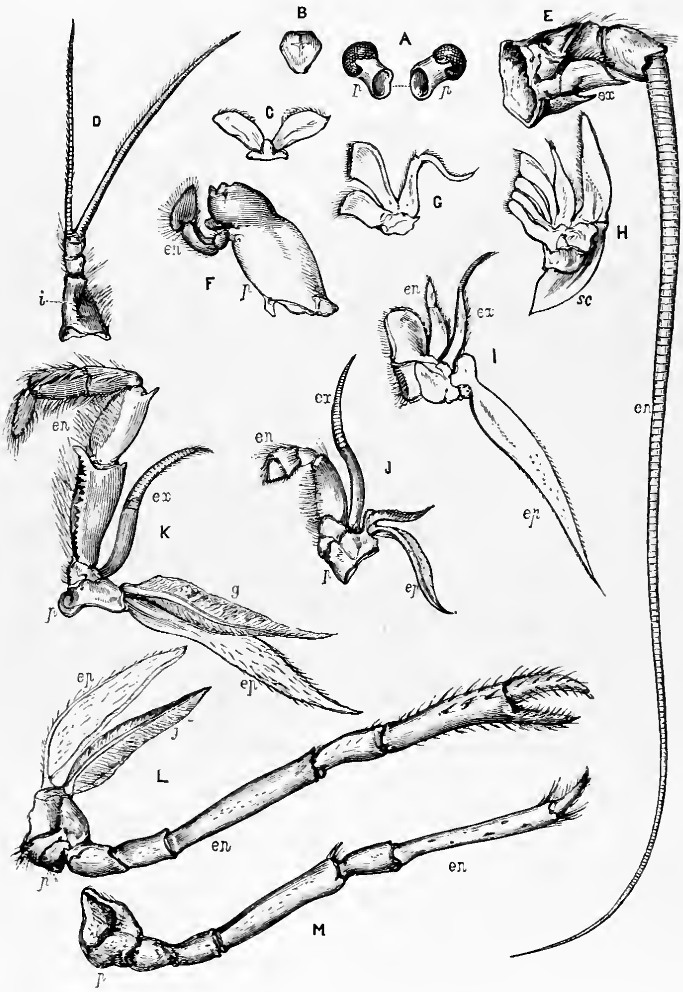

Fig. 5.—Appendages of one Side of Lobster's Head and Chest, from Before Backwards.

(A) Eyes borne on Stalks; (B) Labrum; (C) Metastoma; (D) Antennules; (E) One of the Antennæ; (F) A Mandible; (G) One of the First Pair of Maxillæ; (H) One of the Second Pair of Maxillæ; (I) One of the First Pair of Foot-jaws; (J) One of the Second; and (K) one of the Third Pair of Foot-jaws; (L) One of the Third Pair of Walking-legs of the Female; (M) One of the Hindmost (fifth) Pair of Walking-limbs of the Male; (*ex*) Exopodite; (*en*) Endopodites; (*ep*) Epipodite; (*p*) Protopodite; (*g*) Gill; (*i*) Opening of Auditory Sac; (*sc*) Scaphognathite.

The three first pairs of walking-legs also differ from the two hindermost pairs in being provided with "nippers" at their extremities, the "nippers" being very large in the foremost pair of legs.

We have thus seen that the walking-limbs of the five hindmost chest-joints are simply modified appendages resembling those of the abdomen. The three front joints of the chest—the seventh, eighth, and ninth of the body—bear curious organs, named *foot-jaws*. In these latter organs, we see extremely well exemplified the transition from a walking-limb to a jaw. The hindmost foot-jaw (K), that of the ninth segment of the body, is like a walking-limb. It has a long *endopodite* (*en*), but, in addition, develops a small exopodite (*ex*) not seen in the legs, and has attached to it a gill and an epipodite. The foot-jaw (J) in front of this, or that belonging to the eighth joint of the body, is less like a limb, its endopodite having become shorter and thicker than that of the preceding foot-jaw. And the third foot-jaw (I), that of the seventh joint (or first joint of the chest), resembles a jaw more closely than a limb, and has its protopodite quite jaw-like, its exopodite (*ex*), endopodite (*en*), and epipodite (*ep*) being well developed. No doubt can therefore exist that the eight pairs of appendages of the lobster's chest are modelled on an exactly similar type to those of the tail.

The head, amalgamated with the chest, presents six joints for examination, and necessarily six pairs of appendages. Begin with the hindmost appendages of the head, as before. We shall find that the modifications which these organs undergo, fit them as jaws for the mastication of food, or as organs of sense; the lobster's jaws and sense-organs thus corresponding in position, although not in nature, to the similar organs of higher animals. In the young state, the resemblance between jaws,

foot-jaws, legs, and swimmerets is very close; and hence you are prepared to find the same type of appendage prevailing in the jaws and other head parts, as in the swimmerets. The sixth or last joint of the head bears, in its appendages, a pair of jaws named *maxillæ* (H), and the fifth joint possesses a pair of like organs (G). In each jaw or "maxilla" we can trace all four parts—protopodite, endopodite, exopodite, and epipodite—seen in the other appendages. The hinder pair of maxillæ, it may be noted, bear each a very much enlarged epipodite, which is used as a scoop or baler (*sc*) for throwing the water, which has been used in breathing, out of the gill-chamber. Next in order, on the fourth joint of the head, we can discern a pair of very hard, limy jaws. These are the *mandibles* (F). Each mandible is simply a large protopodite, with a small endopodite, named the *pulp*, said to be used for directing food into the mouth, which opens just between the mandibles. In the mandibles, therefore, neither exopodite nor epipodite have survived. A little upper lip and a lower lip (B C) exist in the lobster, but these are mere developments in the middle line of the body—like the front beak of the shell and the telson—and are not in any sense to be regarded as appendages.

Three joints of the head remain for examination. The third of these possesses as its appendages a pair of very long *feelers* named *antennæ* (E). Each feeler is simply a long endopodite with a protopodite at its base—thus resembling the walking-leg—along with a small scale-like exopodite. Then come the lesser feelers or *antennules* (D), borne on the second joint of the head, each of the lesser feelers consisting of protopodite, exopodite, and endopodite, and being thus a double organ instead of a single one like the greater feelers. The first joint of the head bears a pair of movable, stalked, and compound eyes; and it forms not the least curious result of our investigations when we discover that the *eye-stalks* (A) of the lobster represent *protopodites* which have been alone developed, to the exclusion of all other appendages.

Having thus reviewed the general and external anatomy of the lobster, we may pause in our investigations to consider briefly the results to which our studies have led us. We find thus, firstly, that the lobster is an animal whose body consists of some twenty joints. Then we saw that of these joints the most distinctly marked were those of the tail. The plan of a tail-joint was next examined, and we then discovered that all of the tail-joints were modelled on this single and uniform plan. Proceeding to the fore part of the lobster's body, we discover that this consists of the animal's head and chest, the fourteen joints of which are firmly united. But from a knowledge of development, and from a comparison of the appendages of these joints, we learn that the head and chest segments are similar in essential nature to those of the tail, the appendages of the front segments having undergone modifications which adapt them for their various functions of walking, chewing, feeling, &c. Thus we see that the lobster's body is simply a collection of joints of uniform nature. In other words, the segments and appendages of its body are said to be strictly *homologous*—they are built upon one and the same structural plan. So that, as far as the appendages are concerned, their functions form an immaterial consideration. Part of the organ which is a "swimmeret" in the tail becomes a leg in the chest; and the same type of organ becomes a feeler, a jaw, or an eye-stalk, according to its situation in the body of this curious animal.

The outside anatomy of the lobster, however, forms but the preface to an understanding of its internal mechanism. Occasionally the man of science receives aid in his researches from very unlikely and humble sources; and on this principle I may advise my readers, who may wish to gain a general idea of the internal disposition of the lobster's parts, to glance at the longitudinal section of the animal made by the knife of the fish-dealer or cook, as he bisects the boiled animal for supper (Fig. 6). In such a section, where the parts have

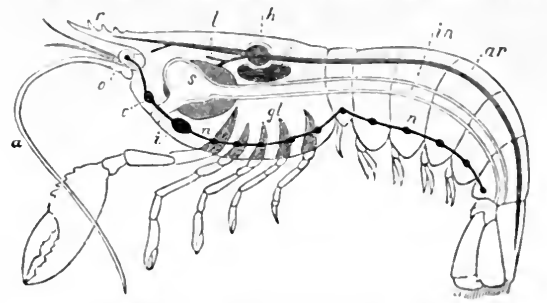

Fig. 6.—Longitudinal Section of Lobster.

(*a*) Antenna; (*r*) Rostrum; (*o*) Eye; (*s*) Stomach; (*in*) Intestine; (*h*) Heart; (*l*) Liver; (*nn*) Nervous Ganglia; (*gl*) Gills; (*c*, *i*) Chief Nervous Masses; (*ar*) A Main Blood-Vessel.

been consolidated by boiling, and especially if the dissector's knife has been keen, we may observe the digestive system lying in the middle of the body. We see that the interior of the head and chest is occupied by the various digestive and other organs of the animal, including a stomach (*s*), intestine (*in*)—running straight to the "telson"—and a large liver (*l*). Nearest the back, within a sac or bag

named the *pericardium*, lies the *heart* (*h*), which, by its constant pulsation, distributes pure white blood to every part of the body.

When we carefully cut away the sides of the carapace, or great "head-shield" of the lobster, we bring into view numerous little conical bodies attached to the bases of the legs, and contained within a very well defined space or chamber. These are the *gills* (*gl*) of the animal, numbering some twenty on each side. Each gill resembles a bottle-brush in structure, in that it consists of a central stem, to which a large number of delicate leaflets are attached. Into the gill, the impure blood passes, and circulating through the delicate leaflets, is brought in contact with the life-giving oxygen contained in the water admitted to the gill-chamber.

This water flows in by the narrow cleft or slit existing at the bases of the legs, whilst it is being constantly baled out by the action of the "balers" or "scoops," already alluded to as being borne by the second pair of *maxillæ* (Fig. 5, H) or lesser jaws.

The vertical section of the lobster, showing us his internal anatomy from head to tail, also demonstrates to us the source of the active movements of the lobster. In such a half-lobster, we may see very clearly that the lobster's tail is but a mass of muscles, these organs being disposed in definite bands or layers. When we contemplate this immense development of muscle, we are at no loss to account for the powerful stroke of its tail and its fin, which sends its possessor backwards with a swift movement through the water. Nor can we wonder at the power of the nipping-claws when we discover by an investigation of their savoury contents, that

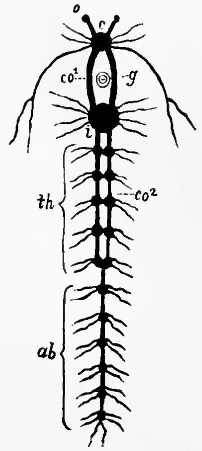

Fig. 7.—Nervous System of Lobster.

(*o*) Branches to Eyes; (*c*) Chief Nervous Mass; (*i*) Nerve Mass below Gullet (*g*); (*th*) Nerves of Chest; (*ab*) Nerves of Abdomen; (*co*¹, *co*²) Connecting Nerve Cords.

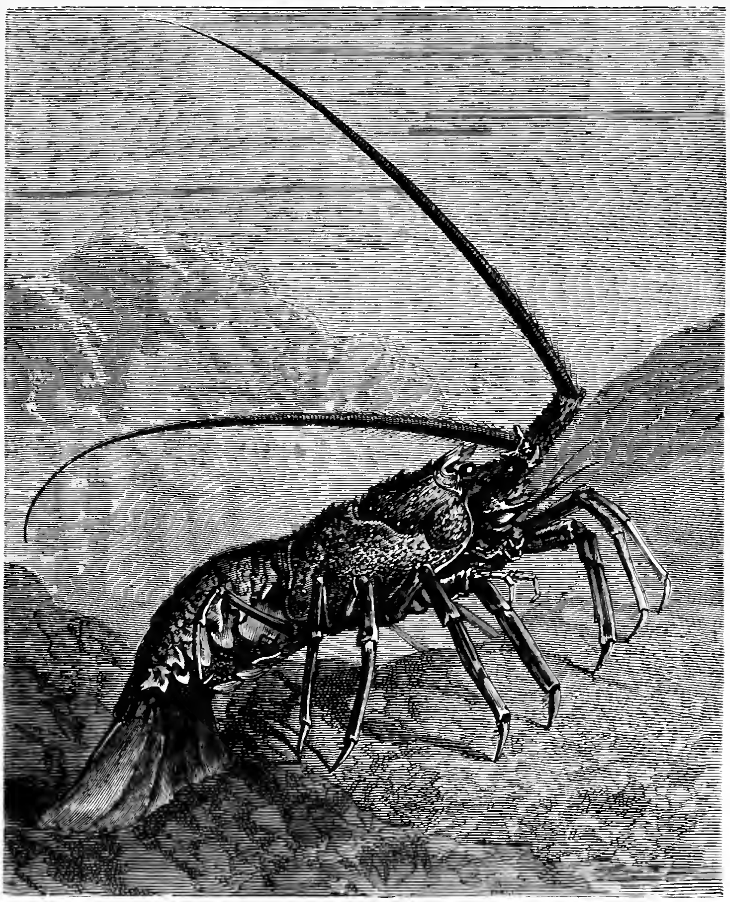

Fig. 8.—The Sea Cray-fish, or Spiny Lobster (*Palinurus vulgaris*).

the edible substance of the claws consists of muscular tissue. It is clear, however, that muscles will move only when stimulated in some fashion or other, and that, in short, the internal mechanism of the lobster, and of all other animals, demands some guiding and directing power. Such a power is supplied by the *nervous system*, which exists practically as a double chain of nerves and nerve knots (or *ganglia*), lying on the floor of the body (Fig. 7). If, in the lobster whose sensation has been deadened, we expose the nerves near the tail and irritate them, as by pinching them, we shall produce strong contraction of the tail-muscles as the result. In addition to supplying the muscular system of the lobster, it need hardly be remarked that from the nervous system is derived the power of seeing and hearing and feeling, possessed by the lobster in common with higher animals. The lobster's eyes, as already remarked, are large and compound, and are borne in eye-stalks. The ears are contained within the last joints of the lesser pair of feelers, and consist of peculiar sacs or bags containing fluid and solid particles. This arrangement is placed in contact with the nerve of hearing, and gives rise to the sense of "sound" when vibrations are received by the "auditory sacs," as the "ears" of the lobster are named.

Such is a brief outline sketch of what may be learned regarding the anatomy of a lobster. The details thus furnished may, it is hoped, pave the way towards the acquirement of a fuller knowledge, not of the lobster merely, but of other forms of animal life. No fact in science remains isolated from its neighbour-facts; and it may be pointed out by way of conclusion, that the study of a lobster forms a solid starting-point for the appreciation of the constitution of the animal kingdom at large.

For example, we have ascertained that the lobster is an animal possessing, (1) a jointed body, (2) a heart lying *dorsally*, or nearest its back, (3) a digestive system in the middle, (4) a nervous system *ventrally*, or on the floor of its body, (5) appendages in pairs, and (6) jaws existing as modified limbs. This information affords the basis for our understanding, as the result of further study, that the lobster does not stand alone in the possession of these characters. All crabs, barnacles, water-fleas, shrimps, &c., agree with the lobster in the possession of these essential features, and so also do insects, spiders, centipedes, and other animals less familiar to ordinary readers. We thus discern that a large number of animals exhibit beneath wide diversities of structure a broad likeness in the arrangement of their parts and organs, and such animals we group together to form a sub-kingdom or type of animals. Recognising this principle of detecting such likenesses, it becomes easy to classify animals which are truly related to each other. The student thus begins to see that what are known as "the great types of animal life" are simply the zoologist's expressions of the close relationship which can be shown to exist between certain groups of animals; whilst he also gains in such a study no mean idea of the true constitution and arrangement of one great aspect of the animal creation.

RUST.

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RUST: it is a very simple word, and there is no doubt but that every one would say he understood perfectly what it meant; however, on consideration it will be shown that its meaning is not so very simple, and that it is a short text upon which a rather long sermon can be preached. Even its primary meaning is not so simple as it at first appears, for on referring to the dictionary we find that "Rust" is derived from a Saxon word, and is defined to be—1. "The desquamation of old iron." 2. The tarnished or corroded surface of any metal. 3. Loss of power by inactivity. 4. Matter bred by corruption or degeneration. With the third of these meanings we have at present nothing to do, but all the other three are included under the action which we call *rust*. The word reasty, as applied to fats, more commonly to bacon fat, means, as given in the dictionary, that it is "covered with a kind of rust," and this is what is implied by the expression "bred by corruption or degeneration." Two very beautiful lines by Coleridge embody the idea of both these changes in matter which will be treated of in this and another article:—

> "The knights are dust
> And their good swords are rust."

The word rust is usually applied to the tarnish

which, by exposure to some influence, appears on the surface of metals, and into the nature of this rust we shall first inquire. If a piece of clean, bright iron be left exposed to the air, we find that in a short time it is covered with a red or brown substance. This coating is formed more quickly in damp air or in the presence of water, and more rapidly in warm than in cold weather. In a tropical climate it is impossible to keep iron or steel goods for even a very short time without their rusting, and this rusting is much more rapid in damp than in dry countries of that region; at Zanzibar, on the east coast of Africa, I have been informed by a relation who lives there that knives and all steel articles rust at once, and that it is most difficult to keep them clean and fit for use. Iron goods of all kinds on their way to the tropics rust, and the best means known are usually employed to retard as much as possible this destructive action. From what has been stated it is clear that three things are necessary to cause iron to rust; for if rusting takes place more rapidly in warm than in cold climates, temperature must have something to do with it; and if moisture accelerates the action, it must have some effect in producing the result; and moreover, there must be something in the air which lends it help, for if iron be kept out of contact with air it will never rust—*i.e.*, it will never rust in the sense in which we are now regarding rust. Some very simple experiments can be performed to prove the truth of these assertions, and it would be well for those interested in the subject to try them. And thus, by the way, a very sound and considerable knowledge of scientific facts can be gained by simply verifying by experiments statements which we read, when those experiments can be performed easily and without danger; and by experimenting on simpler things, facility in manipulation is acquired, so that in time more complicated operations may be performed, and the interest which these engender leads the mind to a love of science, and in many cases, according to the writer's experience, lays the foundation of very considerable scientific attainments. These remarks apply more especially to young people, who will, I presume, be among the readers of this article, and I can assure them that it will well repay them to act upon the suggestion which has been thrown out. Now to begin. Take a wide-mouthed bottle, or even a common physic-bottle will do; let it be quite dry. Pour carefully into it some oil of vitriol so as not to wet the mouth or sides with it; this can be done by using a suitable funnel which can be bought at a chemist and druggist's for a few pence; the funnel is of the shape shown in the illustration (Fig. 2). Let the oil of vitriol occupy about one-fourth of the bottle, then tie to a soft cork, which can be pressed tightly into the bottle, a piece of iron wire which has been cleaned and made perfectly bright. The iron wire should be tolerably thick, so that its surface may be easily seen, and should be just long enough that it may hang in the bottle a quarter or half an inch above the oil of vitriol—for it must *never* touch it; then press the cork tightly into the mouth of the bottle, and if there is any chance of its not being tight enough to exclude air, cover the cork down to the glass with melted sealing-wax (Fig. 1). The iron wire may be bent in the form of a coil, or it may be of any desired form, but care must be taken from the first to keep it out of contact with the oil of vitriol. As long as the bottle remains closed the iron will not rust, and this because no moisture is present. It does not matter to what temperature it is exposed, and it would be well to expose it from time to time to different temperatures in proof of the fact that temperature does not cause iron to rust, even in the presence of air, if moisture be not present. I am now, be it understood, using the term rust in the ordinary sense of the word—*i.e.*, common red iron rust. It may be well to mention why, in this experiment, moisture is absent. All ordinary atmospheric air contains moisture, and the air when first shut in the bottle contained moisture; but the oil of vitriol has a strong affinity for moisture or water vapour, and when in contact with it always absorbs and fixes it, so that the oil of vitriol, which is put into the bottle, takes up the moisture and so dries the air. If it be desired to prove experimentally that oil of vitriol does absorb moisture from the air, it can be easily done by putting some into a saucer, placed in a scale and balanced by weights; if the scales be left in the air, the pan containing the oil of vitriol will gradually descend, showing that its

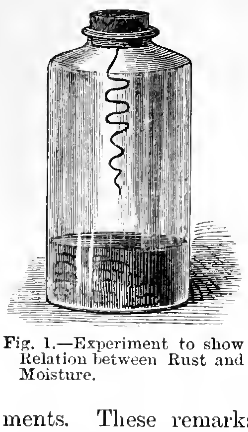

Fig. 1.—Experiment to show Relation between Rust and Moisture.

Fig. 2.—Tulip-shaped Funnel for pouring Oil of Vitriol into a Bottle without wetting the Mouth or Sides.

contents have increased in weight. This experiment proves that moisture or water is necessary to the rusting of iron or steel.

And now I will describe another experiment which proves that the presence of air is equally necessary to produce rust. Into the same kind of bottle put a mixture of lime and sulphate of iron or green vitriol. Make the mixture in the following way :—Green vitriol is a pale bluish-green crystalline substance. Reduce the crystals to a rough powder in a mortar, and then rub up with them about half their bulk of common lime; the mixture will assume a dark green colour. A little water may be added and a small quantity of sawdust to keep it from caking. Put this quickly into the bottle, filling it to about one-fourth of its contents. This operation should be performed quickly. Then plunge in the cork with the iron attached, and cover it well, and also the upper part of the neck of the bottle, with melted sealing-wax. As long as the sealing-wax and cork keep out the external air, so long will the iron inside remain without rusting. Here, as in the last experiment, changes of temperature will produce no effect on the iron. The mixture, or rather the sulphate of iron in the mixture, put into the bottle is brought into such a condition by the lime that it absorbs from the air, in the bottle, that constituent which is the principal agent in causing rust. A little later on in this paper I will treat of this agent and its action. By what has been just described, it will be seen that in spite of the presence of moisture and suitable temperature, iron will not rust if the air in contact with it be deprived of one of its constituents. Another and a very interesting method of performing an experiment similar in its effects to the last, is to shut up pieces of polished iron wire in a glass tube containing water, from which all the air has been expelled by heat. This is too difficult of performance for any one to attempt who is not well versed in chemical manipulation, but for a very small sum it can be done by those who do chemical glass-work. A piece of glass tube, about seven or eight inches long and three-quarters of an inch in diameter, should be softened in a gas-flame, and drawn out as shown in the illustration (Fig. 3). First of all, before the drawing out, the iron wire and some distilled water should be put into the tube, which has been previously closed at one end in the usual way. After the tube is drawn out, the water should be boiled, and the fine end of the tube sealed up with a blow-pipe while the steam is issuing. Now, this is a very difficult operation, quite beyond the powers of even a good ordinary manipulator. I have had such a tube in my possession for a very long time, and the iron in the water has not a single spot of red rust upon it, although the tube has often been heated to the highest temperature it can bear without bursting. And the reason is that no air is present in it, it having been driven out with the steam before the tube was sealed up. These experiments prove most satisfactorily that air and moisture are absolutely necessary to cause red or ordinary rust on iron; therefore, if iron surfaces are kept dry they will not rust, and the practical importance of this lesson is very great; for polished fenders do not rust in a room, the air in which is kept dry by proper ventilation and by fires. Pianos are often spoiled from being kept in damp rooms. Polished steel ornaments, when kept in boxes containing cotton-wool, do not rust—for the same reason, if the wool be kept fairly dry. If iron articles be covered with a paste made of chalk or of lime and water, or if they be put into dry lime, they will not rust. It is sometimes customary to paint over with lime and water the fire-irons and fenders in drawing-rooms when people go out for their summer trips; and on their return they find, when the white is cleaned off, that the articles are as bright as ever. Metallic iron, in the form of wire, is always kept in laboratories; it is very useful to chemists, and in order to prevent it from getting rusty it is kept in stoppered bottles, filled with a strong solution of common washing-soda (carbonate of soda), or with a solution of what is called caustic soda, and these solutions prevent the iron from rusting, because no air is dissolved in the water saturated with these substances, and the substances themselves have no action on metallic iron. It has been stated above that ordinary atmospheric air always contains moisture or water, and all ordinary water contains air dissolved in it; so that if polished iron be put into a bottle quite full of ordinary water, it will rust by means of the air dissolved in the water; but if the water be well boiled and put into a bottle with iron, the iron will not rust until such time as the water shall have again absorbed air, for boiling water drives off air and other gases which may chance to be dissolved in it. It will be remembered that, in the experiment with the sealed glass tube, directions were given to boil

Fig. 3.—Tube melted and hermetically sealed at one end.

the water, and that was to expel the air from it, as well as the air in the tube; and then to close the tube, or seal it up with a blow-pipe, and that was to prevent any air getting dissolved by the water again. The agent essentially necessary to produce rust on iron is contained in the air: it is called oxygen. Atmospheric air is a mixture of gases and other matters. Its composition is pretty uniform all over the earth's surface, and this uniformity of composition is maintained by what is called diffusion. Diffusion is a property which gases, when they come in contact with one another, have of mixing together. By observation, a law of diffusion has been discovered—*i.e.*, the rate at which gases in contact mix together. It is stated to be at a rate inversely proportional to the square root of their densities, which means that a light gas passes more quickly into a heavy gas than the heavy one does into the other. Perhaps an example will illustrate this better. A measure of hydrogen weighs one; an equal measure of oxygen weighs sixteen, both being measured at the same temperature and pressure. If these two gases be contained in two separate bottles, the mouths of which exactly and closely fit one another, and if the hydrogen bottle be placed with its mouth to that of the oxygen bottle, the hydrogen being at the top, it will on examination be found that in a very short space of time the gases will be mixed together in both bottles. Now, the oxygen which was placed at the bottom, and which is sixteen times as heavy as hydrogen, will pass, contrary to its gravity, up into the hydrogen, and the lighter hydrogen will descend into the oxygen. Now oxygen is sixteen times as heavy as hydrogen, volume for volume, and the square root of sixteen is four; therefore the hydrogen will pass or diffuse into the oxygen four times as fast as the oxygen will pass into it. The composition of air is, roughly speaking, as follows:—Four volumes of nitrogen, one of oxygen: four parts of carbonic-acid gas in ten thousand parts of air; a variable quantity of water vapour (some is always present): a very small quantity of ammonia; and a variable quantity of dust, &c., in a state of fine division. The oxygen, it appears, does not hold a very large proportion to the nitrogen, but its activity is so great that this quantity is sufficient to effect completely the offices which it has to perform in nature; and these are most important, for it is the agent which supports life—without it we could not live many seconds. It also supports combustion: by its means fires, gas, and candles burn; moreover, though it supports life in the living animal, it is the agent which causes corruption and decay in the bodies of animals when dead. From the first breath we draw, it supports and strengthens us in our growth till what is called the period of middle life; and then, though still sustaining us, it produces, as age advances, those changes which we speak of as decay of nature, till at last it finally reduces our mortal bodies to that state of dust from which they were originally formed. Oxygen unites with other substances whether they be elementary—that is, simple—or compound, and, in union with these, forms a very considerable proportion of the earth on which we dwell. The flints or stones which we see in the roads, the sand on the sea-shore, the soil in which vegetation flourishes, the materials of which our houses are constructed, are all formed to a great extent of this substance, chemically combined with other elements. A fifth of the volume of air, we have seen, is oxygen; and in every eighteen parts of water by weight, sixteen are oxygen.

It would take us beyond the subject of this article if we were to trace the still further occurrence of this important substance in nature. We will therefore confine our observations to its properties—one of the most energetic of which is its power of unity with other bodies—and the conditions under which these properties are usually manifested.

Iron-rust is a compound body, formed by the union of iron with oxygen. I have already shown what promotes and what retards the rusting of iron, and this was done for the purpose of illustrating the more scientific part of the subject, and to prepare the reader unacquainted with scientific matters for a more clear conception of what might have been difficult had not such simple hints been first given. It has been seen that dry iron will not rust in air—that is, oxygen will not unite with iron without something to promote that union. The addition of a little water causes rust to be formed; therefore water is an agent which will produce this result when oxygen and iron are in contact. It has also been stated that temperature has an accelerating influence, for rusting takes place more rapidly in warm than in cold climates.

I have not described an experiment to prove this, as it would be difficult of execution, and my desire is that all experiments described should be simple. Oxygen unites with iron in several proportions, but always in the proportion by weight of 56 of iron to 16 of oxygen, or in multiples of these numbers. The proportions in which iron and oxygen unite to form common red rust are 2 (56) parts by weight of iron and 3 (16) parts by weight of oxygen. And

this is the oxide (for when oxygen unites with another substance the product is usually called an *oxide*), which is eventually formed when iron is left exposed to air and moisture. I say eventually, because no doubt another oxide containing less oxygen is first formed, and this afterwards becomes red rust, or the higher oxide. It is customary to speak of an oxide as a higher oxide of a body when it contains more oxygen than the lower. The process which is supposed to take place when iron rusts is somewhat complicated, but I will endeavour to make my description of it as clear as possible. Imagine a piece of clean iron to be acted upon by air—*i.e.*, by the oxygen in the air—in the presence of moisture, and suppose fifty-six parts by weight of its exterior surface to become united with sixteen parts by weight of oxygen, an oxide will be formed different in composition to red rust, which is composed of 2 (56) of iron to 3 (16) of oxygen, and therefore contains one-third more oxygen in proportion to iron. Now, imagine the oxide first formed to take up one-third more oxygen, it will be at once converted into red rust; in time the entire surface of the iron will be covered with this substance, and some of it will be in contact with the metallic iron beneath it. It is supposed that the red rust in contact with the iron gives up one-third of its oxygen to the iron, and so forms again on its metallic surface the first oxide, and that red rust which gives up its oxygen again becomes reduced to the first oxide. We will represent it by figures, for this seems to be the clearest way to make it understood :—

56+16 is the composition of the first oxide.
Take 2 (56+16), double the quantity of first oxide,
And add 16 of oxygen;
Then we get 2 (56)+3 (16), which is the composition of red rust.

Now if this red rust gives up 16 of oxygen to 56 more of iron, the whole becomes 3 (56 + 16), or three times the quantity of first oxide. Now if this quantity be doubled—that is, if we take 6 (56 + 16), it will take up 3 (16) more oxygen, for as we have seen, 2 (56+16) always takes up 16 of oxygen, and will become 3 [2 (56) + 3 (16)] of red rust, and this action keeps going on till the whole of the iron is converted into red rust. The action is more rapid at first, for the dense red rust forms a sort of protection to the parts underneath, so that the oxidation proceeds more slowly, though it is never absolutely arrested. From this it appears that the higher oxide of iron in contact with the iron acts as a carrier of oxygen from the air to the iron beneath, and this is why iron, in time, gets totally destroyed by rust, whereas other metals, such as lead, copper, and zinc, do not. This will be fully understood when we come to the consideration of the rusting and corrosion of these metals.

For the better understanding of the rusting process, it will be necessary to give a little time to study the first oxide of iron, as I have hitherto called it. It is called protoxide of iron (sometimes ferrous oxide), the termination *ous* of the word ferrous implying that the substance contains less oxygen than iron rust, which is called ferric-oxide, and sometimes sesqui-oxide of iron. It is called sesqui-oxide because it contains half as much oxygen again as the protoxide does; and the word protoxide means the first oxide. The protoxide of iron, although formed by the direct union of iron and oxygen, is not persistent—that is, after formation it does not continue as protoxide, but is immediately changed by addition of oxygen into the higher oxide, so that we say ferrous oxide has a great affinity for oxygen. Ferrous oxide is obtained by precipitating it from a solution in which we may consider it to be dissolved in an acid liquid. If metallic iron be put into dilute oil of vitriol an effervescence takes place, owing to a gas being given off, and this gas is hydrogen. If after the iron is dissolved the liquid be evaporated by boiling till the residue is very concentrated, and be allowed to cool, green crystals will be formed, and these can be collected and dissolved in water, and the solution contains ferrous oxide dissolved in dilute oil of vitriol. If the oil of vitriol be taken away, ferrous oxide, which does not dissolve in water, will be thrown down or precipitated. It would be well to perform an experiment to show this, but it is not necessary to take the trouble to dissolve iron in dilute oil of vitriol, for crystals of this green substance, which is called green vitriol or sulphate of iron, can be obtained at any druggist's. Some test-tubes should be got from the same shop; those about five inches long are the most convenient. Put some of the sulphate of iron into a test-tube with some water, and when it is dissolved pour into it a solution of ammonia, and immediately a green precipitate will be thrown down. This precipitate is one containing ferrous oxide, but if it be shaken about in the test-tube, it will be found to change colour in the upper part, where it comes into contact with the air; it will become of a dirty yellow colour, and this because it is being changed into ferric oxide. This action is better seen if, after the precipitate be formed, the

whole contents of the test-tube be poured on a filter-paper, placed in a funnel, or even it can be poured on to a white plate. In a very short time all the green precipitate will cease to be ferrous oxide, and will be changed into ferric oxide by the action on it of the oxygen in the air, and its colour will be yellow. But then it will be said—Is this the same substance as iron-rust? for iron-rust is of a brown-red colour. No, it differs from iron-rust in this respect—with it is chemically combined water, and because it contains this chemically combined water, it is called a hydrate; but this water is not combined with it nearly as firmly as the oxygen is with the iron, for if it be gently heated the water can be driven off, and then the yellow powder will be seen to change colour, and look like iron-rust, and will be, in fact, the same substance as iron-rust. The last part of this experiment can be easily performed by putting the yellow powder, when it is dry, into a little white dish, called a Berlin dish; this can best be held in a pair of metallic tongs, called crucible tongs, over a gas or spirit lamp, and as the yellow powder becomes hot it will pass through various tints of brown until it becomes of the brown-red colour of iron-rust. There are conditions, however, in which the ordinary rusting process produces a yellow and not a brownish-red body. For instance, new rails may be seen lying by the railway covered in part with a yellow rust; but, though at some future time I may treat of it, the subject is so interesting and new, that to discuss it here would lead us too deeply into scientific questions. The colours known amongst artists as "Mars' colours" are all oxides of iron of different compositions. The yellow tints are hydrates; the various reds have been more or less heated, and therefore resemble closely common iron-rust, and the purples have been heated to a very high temperature, and are composed of the red oxide and another, the composition of which will be explained directly. Certain substances cause rust to be formed on the surface of iron with great rapidity; vinegar, for example, is known to rust dinner-knives very quickly. Salt also accelerates rusting; their action in producing rust is somewhat complicated, and its explanation is beyond the scope of this article. When iron is heated in the fire and exposed to air, a scale is formed upon it which can be easily removed. These scales are found in abundance in smithies round the anvils upon which the hot iron is beaten, and they are therefore called smithy scales. These scales are not iron, but are an oxide of iron of a grey colour, almost black, therefore called black oxide of iron. The composition of this oxide differs from that of those we have been considering; three times fifty-six parts, by weight, of iron enter into combination with four times sixteen parts, by weight, of oxygen to form it, therefore in it iron and oxygen exist in proportions similar to the sum of the other two oxides. The protoxide contains 56 of iron to 16 of oxygen, and the sesqui-oxide 2 (56) of iron to 3 (16) of oxygen. It is supposed by some to be simply a mixture of the two oxides; whether this is so or not we will not discuss here. An oxide of iron of this composition is found native in Sweden, and having magnetic powers, is called loadstone. A piece of steel rubbed with it attracts needles and pieces of clean iron, hence this native oxide is called magnetic oxide of iron, and the same name is often applied to the black oxide, however it be formed. Large quantities of black oxide of iron are found on the sea-shore in New Zealand, in the form of small grains like sand; it is therefore called "black sand." This oxide is not affected by moisture; though it contains less oxygen than the ferric oxide, it is not by air, in the presence of moisture, converted into that oxide. A very simple way of making it is to put small pieces of clean iron into an iron pipe, which should be made red-hot, and then to pass steam through the pipe. The properties of this oxide will be more fully considered, and the best way to make it, in a future article on the prevention of rust on iron.

Other metals besides iron are subject to rust or corrosion; silver tarnishes on exposure to air, but the agent which produces this is not oxygen but sulphur. Silver does not oxidise when exposed to oxygen, but it very readily unites with sulphur if warmed with it. Sulphuretted hydrogen gas blackens silver at once, so that if a small piece of sulphide of iron be put on a shilling moistened with water, and a drop of hydrochloric acid be poured on the sulphide of iron, sulphuretted hydrogen gas will be set free, and the shilling will be spotted brown and black in a very short space of time. Now, sulphuretted hydrogen occurs in small quantities in the air, and its effect is to tarnish silver. It has probably been often noticed that, where silver spoons are used in eating eggs, the bowls become stained brown, and that it is very difficult to clean them. This brown tarnish is owing to the formation of sulphide; for eggs contain a large quantity of sulphur, which gives rise to their offensive smell when they "go bad," owing to the formation in them of sulphuretted hydrogen gas. A little dilute aquafortis will

remove the tarnish from silver very rapidly. If this method be employed, the silver should be immediately washed thoroughly in water. Copper forms a rust which is usually green; this is not, however, an oxide, but a carbonate. Copper is readily tarnished in the presence of acids, especially the acid of vinegar; also in the presence of fats, so that copper cooking-utensils should always be freed from grease, which promotes the rusting of the metal, and so causes its introduction into food, where it never ought to be, as copper salts are very poisonous. The beautiful green tints of old bronze are due to the rusting of the copper, which is the principal constituent of bronze. But rusting in copper does not progress as it does in iron, so that a film of it protects the copper beneath from further destructive influences. The same also is the case with lead; its rust is white, and, like that of copper, is a carbonate of the metal. When lead is once coated, further action is arrested, and it is well known that lead roofs have lasted for centuries. Zinc, on exposure, in time becomes tarnished with a whitish substance, which is the oxide, and as zinc forms but one oxide there is no passage of oxygen from it to the zinc beneath, as is the case with iron, so that its rusting is not continuous. Gold and platinum do not rust at all, neither does aluminium, hence it has been used for making aluminium bronze for watch-cases, pencil-cases, &c. These, however, do tarnish slightly in time, but this is owing to the copper with which the aluminium is alloyed. The metal nickel is now used for coating iron, and the coated articles retain their brightness; for nickel does not tarnish on exposure to air.

The space allotted to this article is now exhausted. We have considered here how the good knights' swords became rust; at some other time we will consider how the knights themselves became dust.

A GLASS OF WINE.

By Professor F. R. Eaton Lowe.

When the Tartar brings out his oldest arrack, the South American settler his very best chica, the simple African his choicest palm wine, and the European his bottle of "generous" port, they are doubtless actuated by the best intentions. But whether their hospitality might not be exhibited in a more suitable form is a question that is acquiring, almost daily, increased importance. However, we are not called upon to discuss it here, and from *our* special standpoint we may, perhaps, spend half an hour not unprofitably in considering the chemical properties of a glass of wine, and in tracing its action on the human economy.

Common alcohol—the intoxicating element in beer, wine, and spirit — is only one of a large chemical group, and is known as *ethyl* alcohol, to distinguish it from other fluids of a similar volatile nature obtained from other sources. Thus, there is *amyl* alcohol obtained by the distillation of potato starch, and *methyl* alcohol, or wood-spirit, obtained by the dry distillation of wood. Both of these latter kinds are much cheaper than ethyl alcohol, and are consequently much used in adulterating wine and ardent spirits. Alcohol is produced by the fermentation of sugar, and any substance containing sugar is capable of yielding it, by applying a ferment, and afterwards distilling off the vinous product. In general, the larger the amount of sugar in the fruit employed in the process, the greater will be the quantity of alcohol it will afford, if the fermentation is permitted to go on till all the sugar is expended.

Thus, the luscious grapes of Spain and Portugal yield strong wines, while the more acid vintages of Germany and South-west France produce wines of only half the alcoholic strength. What are called British wines, again, as currant, gooseberry, and orange, are weaker still, as these fruits have very little saccharine matter, and a large proportion of acid, so that sugar is added to disguise the excess, and sometimes a table-spoonful of spirit to each bottle to delay acetic fermentation. Sugar exists in grapes and fruit generally in the form of glucose, and is composed of six equivalents of carbon, twelve of hydrogen, and six of oxygen. Alcohol is composed of the same three elements, but it has only two equivalents of carbon, six of hydrogen, and one of oxygen. During fermentation, then, the sugar has lost several equivalents of each element by disengaging carbonic acid, water, and some other products. The frothy scum which always accompanies the process is produced by the passage of

the escaping carbonic acid through the gummy and saccharine matters of the fermenting wort, or *must* as it is termed by the vintners.

Ethyl acts the part of a base, because other compounds besides ethyl alcohol are built upon it. Thus, common alcohol is ethyl plus the elements of water, and is, therefore, called hydrated oxide of ethyl. We may exchange the elements of water for iodine, chlorine, and many metals, and thus by substitution get ethyl iodide, ethyl chloride, zinc ethyl, and so on. If we put a glass of port or sherry into a retort, and boil it, the vapour or distillate which passes over is spirit of wine, or alcohol containing about 20 per cent. of water, to which it clings so tenaciously that repeated rectification will not reduce the quantity to less than 10 per cent.

Absolute alcohol, or perfectly pure spirit without water, is a curiosity of the chemist's laboratory, and is prepared by distilling (Fig. 1) the strongest spirit of wine with some caustic substance, such as potassa, which has a stronger affinity for water than the alcohol has, and immediately combines with it when brought into contact. Ordinary spirit burns with a pale blue flame, giving out a strong heat, and depositing little or no carbon or soot. On this account it is very suitable for combustion in the small glass lamps used in conducting experiments on a small scale. It will float on water, as its specific gravity is less, in the proportion of 792 to 1,000. The weight of a spirituous liquor relatively to water gives an estimate of its alcoholic strength; and in this way the Excise officers calculate the amount of duty to be levied. The instrument used to measure specific gravities is a hydrometer of brass, with a bulb at one end, weighted, to enable it to float in a vertical position in the liquid under examination. The heavier the liquid, the more the hydrometer will be buoyed up, and the lighter it is—or, in other words, the greater the proportion of alcohol, the deeper will the instrument sink. In making these calculations, temperature must be taken into account, as heat expands alcohol considerably, and thereby lowers its specific gravity. Ethyl alcohol boils at a much lower temperature than water, that is 172° as compared with 212°. Methyl alcohol or wood-spirit boils at a still lower temperature—viz., 140°; and if some of it be put in an exhausted glass tube, it will begin to bubble as soon as the vessel is grasped by the hand. An instrument exhibiting this phenomenon, and called a "pulse glass," can be purchased for a trifling sum of most of the London opticians. Amyl alcohol or potato-spirit, on the other hand, boils at a very high temperature—viz., 270° or 58° above the boiling-point of water. On account of the expensive nature of spirit of wine, the Excise allows the admixture of 10 per cent. of wood-spirit, or methylated spirit as it is sometimes called, for scientific purposes.

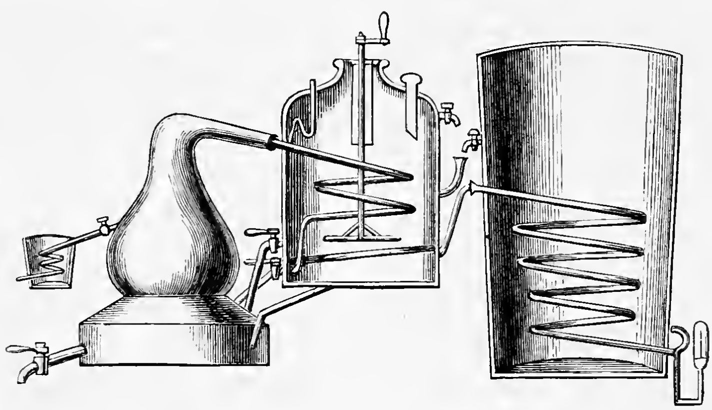

Fig. 1.—Distilling Apparatus.

In wine-making, it is unnecessary to add a fermenting substance, as in the case of beer, for the fruit contains sufficient nitrogenous matter in the shape of gluten, which speedily undergoes decomposition, and communicates its state of change to the associated sugar. The grapes are gathered and pressed during the day, and left to ferment in the night; but the process is not complete, nor the wine ripe, till the middle of the succeeding winter.

A few days suffice for the subsidence of the more active fermentation, and the liquor becomes clear and loses sweetness, indicating that the greater part of the sugar has been transformed into alcohol and carbonic acid. It is then racked off from the lees, and run into tuns for the second, or what we may call the quiescent, stage of fermentation. In February it is run into casks, and is then fit for sale as new wine. Some minor changes still take place in the wood. In the first place, there is a certain amount of evaporation of water, so that the wine becomes rather stronger; then a little of the colouring-matter is absorbed by the wood, and the product becomes of a somewhat lighter hue, while a portion of the alcohol by oxidation becomes converted into *aldehyde*, and subsequently, by the appropriation of another atom of oxygen, into acetic acid, of which,

according to Mulder, there are two or three parts in the thousand. If this oxidation were allowed to go on in the open air, the whole of the alcohol would become acetic acid or vinegar, this acid containing one equivalent more of oxygen and two less of hydrogen.

Wine is still further altered by being kept some years in bottle. Evaporation is impossible, so that the wine cannot acquire strength; and the popular notion that wine becomes stronger in proportion to its age in bottle is a fallacy which it is to the interest of the dealer to keep up. The principal changes which take place in bottle, are the deposition of colouring-matter and salts constituting the "crust," and the development of the *bouquet* or peculiar aroma, which is such a distinguishing characteristic of the high-priced varieties.

Red wines contain a blue colouring-matter, which only exhibits its proper hue when thrown down; because, as long as it is in solution, it is reddened by the tartaric acid of the wine, in the same way as blue litmus, or blue cabbage-liquor, which are used by chemists as acid tests. The action of acids upon blue colouring-matter may be illustrated in a very simple manner. We can easily make a blue solution by infusing small pieces of red pickling-cabbage in hot water. A drop of any acid, such as sulphuric acid, or even vinegar, will immediately change the blue colour to red. A blue juice can be expressed from many red flowers, whose hue, as in the case of red wine or red cabbage, depends upon the presence of a vegetable acid. The subsidence of this colouring-matter is due to the insoluble tannic acid and alumina, which are very slowly precipitated, carrying down at the same time the vegetable matter and cellulose, in a finely-divided state. The process by which colouring-matter is deposited may be illustrated by a simple experiment, which requires no manipulative skill for its performance. Make a solution of cochineal by boiling the powdered insects in water. To the dark-red liquid add a small quantity of strong alum solution or cream of tartar, and await the result. You will soon observe that the colouring-matter is being slowly precipitated, and accumulating at the bottom of the vessel, while the solution itself is becoming proportionately clearer, till it finally loses nearly all its colour. The precipitated powder is the famous *carmine*; and colours obtained in this way on a large scale are commercially known as *lakes*. In this case the phenomenon is due to the carrying down of a colouring principle in combination with some animal matter by the slow subsidence of the alumina. The deposition of port-wine crust is effected under precisely similar conditions. In the wine there is the alumina, the acid tartrate of potash, the colouring principle, and the vegetable matter or cellulose instead of the animal matter of cochineal. These constituents are so intimately incorporated that the process of precipitation is necessarily slow, and occupies several years. Tannic acid is a very astringent substance, and communicates the roughness peculiar to new wine. When the insoluble portion of this acid is entirely precipitated, which does not take place for five or six years in the wood, though more rapidly in bottle, the wine acquires that softness of character which, connoisseurs tell us, is one of the principal tests of its excellence. After a certain period, no greater degree of softness can be secured by keeping, but rather an insipidity to which roughness would be preferable.

Tannic acid or tannin is the active principle of oak-bark and gall-nuts, used in the manufacture of black ink; it is also abundant in those excrescences well known as "oak-apples," which are abnormal growths, produced by the puncture of a small insect belonging to the genus *Cynips*. It is of somewhat common occurrence in the vegetable kingdom, and the bitter astringency of fruit, skins, and seeds, especially those of the grape, is due to its presence. Tannic acid has a powerful affinity for gelatine and albuminous matters, with which it forms an insoluble compound; indeed, the manufacture of leather is based upon this property, the tannin of the oak-bark uniting with the gelatine of the skins. The frequent use of very rough wine, or wine adulterated with logwood, in which tannic acid occurs, would have the effect of hardening the throat and palate, by the transformation of the delicate cuticle into a membrane of unusual density and dryness. A characteristic test for tannic acid is the black colour it produces with salts of iron. By this means it may be detected in wine and tea, the depth of shade produced varying with the quantity of tannin present.

The agreeable bouquet or aroma is developed at the expense of the alcohol, and is much improved by age. This accounts for the loss of strength in very old wines, as a portion of their alcohol is decomposed, and becomes aldehyde and ether. The ethers are fluids derived from alcohol by the action of various acids, and are extremely volatile. The ether of the photographer's shop, with the peculiar smell of which we are all of us familiar, is made by acting upon spirit of wine or methylated spirit with strong

sulphuric acid. Hence it is called sulphuric ether. Now there is no sulphuric acid in wine, but there are several other acids capable of acting upon the alcohol. There is tartaric acid, acetic acid, butyric acid, caproic acid, and some others. These acids produce different ethers, which combine to give the much-valued bouquet to old wines; but the principal agent is *œnanthic ether*, which is powerfully aromatic in old ports and sherries.

The bouquet of wines has nothing to do with their flavour, except, perhaps, to deteriorate it; for these ethers, when prepared in a pure state in the laboratory, have by no means a pleasant taste, and their odour is rather disagreeable than otherwise. The flavour of a wine is the aggregate of the flavours of the different acids and salts contained in it; and analysis shows us that the juice of the grape holds in solution a considerable number of substances, amongst which may be mentioned chloride of sodium (common salt), chloride of potassium, phosphate of aluminium, sulphate of potash, tartrate of lime, tartrate of iron, tartrate of alumina, and tartrate of potash. This latter salt usually occurs in the form of the bitartrate, in which the acid is in excess, and then constitutes the well-known cream of tartar or *argol*, often found deposited in wine-casks in the form of small white or reddish crystals. Besides the salts already referred to, there exist in the fresh juice glucose or sugar, gum, and blue or brown colouring-matter, the latter being derived principally from the skins, which, in the case of dark or red wines, are allowed to ferment with the expressed juice.

The lighter-coloured, or white wines, are not necessarily produced from white grapes, but the fruit is carefully pressed to avoid extracting colouring-matter, and the skins are separated before fermentation begins.

Why is one wine sweet and another dry? In the first case, all the sugar is not transformed into alcohol, but part of it remains in the wine after the fermentation has subsided. In the dry wines, on the contrary, the fermenting process has proceeded till the whole of the sugar has been decomposed or split up into alcohol, carbonic acid, and the other acids and ethers already referred to as combining to give character to the wine.

Thus we have sweet sherry and dry sherry, sweet and dry Champagne, sweet and dry Moselle, and so on. Sparkling wines owe their character to the escape of carbonic-acid gas in bubbles, as in effervescing drinks generally. These wines are bottled while active fermentation is going on, so that the carbonic acid is retained in the wine. Sometimes the fermentation is arrested before all the sugar is exhausted: in that case we get a sparkling sweet wine. Thus, in sweet champagne there is one-third of an ounce of sugar to the pint, while we have met with samples that have contained nearly one ounce to the pint. The sparkling wines with which we are most familiar are Champagne, Moselle, and Hock; but there are others of less note, as Hermitage, St. Peray, and White Burgundy. According to the principle just laid down, red wines ought to be susceptible of effervescence by the fermentation of their sugar. Accordingly, such wines are not unknown, as sparkling red Burgundy, which is somewhat of a curiosity here, but much consumed in the district where it is produced. If the fermentation of port were not arrested by the addition of alcohol, that wine would be liable to disengage carbonic acid, especially when new. Some black or red grapes, however, are not favourable to the production of sparkling wines, owing, probably, to the disproportion between their saccharine matter, and the gluten or nitrogenous matter, which, as we have said, is the fermenting agent. The sweet wines are Tokay, Malaga, Samos, Tent, Cyprus, and Constantia from the Cape. The first three are made from dried grapes, and contain four or five ounces of sugar to the pint of twenty fluid ounces; while the three latter hold in solution from two to four ounces of sugar. Roussillon, or French port, is a sweet wine from the extreme South of France, often used, on account of its cheapness, to adulterate genuine port; and Tarragona, or Spanish port, is another sometimes used for the same purpose.

Next in order of sweetness come port and Madeira, which contain about one ounce of sugar to the pint; brown sherry, three-quarters of an ounce; dry sherry, one-sixth of an ounce; while claret, Burgundy, hock, Moselle (dry), Maçon, and other French wines of the same district, have none at all. We now come to the subject of alcoholic strength. This is a matter of some importance to wine-drinkers, as the physiological and psychological effects following its use are mainly due to the spirit it contains, and are little influenced by the acid, sugar, and ethers. As the physical evils attributable to alcohol are augmented exactly in proportion to the strength of the stimulant, it is important that we should know the percentage of that potent agent in the wines most likely to come under our notice. We find, then, that the wines of Spain, Portugal, and the Madeiras, are much the strongest. Port naturally contains about 24 per cent. of alcohol, but its strength is always increased

by the addition of brandy, and almost every shipment to this country is fortified to such an extent that its alcoholic percentage is brought up to 35, or even higher. Much of this is added to arrest fermentation, and thus prevent the loss of sugar. The strongest brown sherries contain the same proportion of spirit as port, and are fortified in a similar manner.

Madeira averages 20 per cent. of alcohol; while the light French and German dinner-wines, as claret, hock, Burgundy, and Rhine wines, possess from 9 to 12 per cent. Champagne is rather stronger, having 14 per cent. of alcohol. The reader may, perhaps, wish to know the relative strength of some other alcoholic stimulants in common use. There is the London porter, for instance, so much appreciated by metropolitan working men, but, perhaps fortunately, unknown in the provinces. Its depth of colour and density, due on the one hand to burnt sugar or caromel, and on the other to gum and extractive matter, are the qualities which appear to recommend it; for, as it contains 98 per cent. of water and but 2 of alcohol, it cannot be called a very powerful stimulant. An ordinary wine-glass holds about two fluid ounces, and the quantity of spirit in an imperial pint of London porter would be three-quarters of an ounce, or a little less than half a wine-glassful. Strong pale ale has 8 per cent. of alcohol, and is sometimes as strong as claret; while London and Dublin stout have 6 per cent. With regard to ardent spirits, rum is the strongest, having 60 per cent. of alcohol, brandy 50 to 55, whiskey 50, and the gin commonly retailed in London little more than 20 per cent., or four ounces (two wine-glasses full) to the pint. The best gin should contain just double this quantity. The proportion of water in wines can easily be calculated when the amount of spirit is known. Thus port, with 35 per cent. of alcohol, will have 65 per cent. of water, claret 90, and Burgundy 88 per cent.

We now come to speak of the acids of wines. The acid which exists in largest quantity is tartaric acid; there are others whose chemistry is still somewhat obscure, but they exist in such small proportions that we need not dwell upon them here. Amongst the most acid wines are claret, Burgundy, hock, and Moselle. According to Mulder, the first holds in solution about 170 grains of tartaric acid to the pint, Burgundy 160 grains, and the rest a little less. Port has only 80 grains, and brown sherry 90 grains. Pale ale contains 40 grains of acetic acid, and cider 120 grains of malic acid in the same quantity. Some French wines, as Beaune, Beaujolais, and others produced north of the Gironde or Bordeaux district, are still more acid than the above, but they are not in much repute in this country.

White wines of the Burgundy district, as Chablis, Sauterne, and Barsac, are stronger than the red, and are justly esteemed for their flavour and freedom from excess of acid. From Germany we derive some of the finest wines with which we are acquainted. Steinberg, Rudesheim, Hochheim, and the world-renowned Johannisberg, are produced in the valleys of the Mayne and Neckar. The last-mentioned district is, perhaps, the best wine-growing country in the world, as its climate is said to be the finest in Europe. The best vineyards here are surrounded by high walls to protect the trees from winds, and the utmost care and vigilance are exercised in the cultivation, in order to secure luxuriance of growth and freedom from partial decay or blight. The produce is necessarily limited,

Fig. 2.—Vine. Flower and Leaf.

and veritable specimens of Johannisberg are somewhat difficult to procure in this country.

The vine (*Vitis vinifera*, Figs. 2 and 3) belongs to the natural order *Vitaceæ*, which contains also

the well-known Virginian creeper. Although found wild in many parts of France, Spain, and Italy, it is probably only an offshoot, and not indigenous in any part of Europe. Its home appears to be the shores of the Caspian Sea, and the south-east shore of the Black Sea, about latitude 37°. Its cultivation in Europe extends as far north as the forty-ninth parallel.

In good situations it will ripen its fruit in England as far north as 51° or 52°, but the berries are very small, and quite unfit either for the table or for wine-making.

The vine is now cultivated in warm latitudes all over the world. On the equator itself, in South America, it is grown for the purpose of making wine, and in Hindostan there are vineyards at an elevation of 8,000 feet above the sea. In Sicily the sides of Mount Etna are planted to the height of 5,000 feet, and the produce is the famous Marsala, or Sicilian sherry, which, by the way, is less likely to be sophisticated than any other wine sold at two shillings the bottle, with the exception, perhaps, of the wines of Bordeaux. The leaves of the vine are five-lobed, the flowers small and green, and the tendrils by means of which the plant climbs issue from the points where the leaf-stalks join the stem.

It only remains to glance very briefly at the physiological effects of alcoholic stimulants. With the moral, social, and physical evils of intemperance we are painfully familiar; but our present purpose is simply to investigate the subject from a chemical and pathological point of view, or to trace the changes which follow the admixture of alcohol with the blood. One of the characteristics of alcohol is its powerful affinity for water. Placed in contact with an animal membrane, it immediately withdraws the water which is an essential component of the structure, and partial or complete destruction of its substance is the result. Now, the human stomach is lined with such a similar tissue, distinguished as the mucous membrane; and upon its healthy condition depends the due performance of the function of digestion.

In the confirmed dram-drinker, this membrane is mottled with inflamed patches; and the intemperate use of the stronger wines is sooner or later followed by a similarly diseased condition. As pure water forms the weightiest constituent of the human body—a man weighing 154 lb. having 111 lb. of water in his composition—it follows that the substitution of alcohol for that element, and its permanent fixation in the blood, must vitiate the condition of every organ, vessel, and tissue containing water as an integral portion of their substance, and seriously interfere with the due performance of their functions.

The great centre of the circulation—the heart—participates in the disturbance. Its action is intensified, and it is called upon to perform one-fourth more work than is ordinarily expected from it; in other words, the rate of its pulsation is

Fig. 3.—An Eastern Vineyard.

increased from the normal number of 100,000 to 125,000 per day. The effect is that the blood is driven with greater force into the minute circulation, where there is insufficient resistance to propel it through the minute veins or capillaries. These little vessels consequently become enlarged and gorged with blood; hence the suffusion and red blotches which advertise the perpetual tippler, and render his appearance so uninviting, especially as the nose is the part usually selected for their display. Till a comparatively recent period, the opinion was universal amongst physiologists that alcohol acted as a respiratory food—that is to say, it was burned in the body like fat or starch, with the production of heat and the evolution of carbonic-acid gas from the lungs. The researches of Dr. Edward Smith proved that under alcoholic stimulus there is a marked diminution in the quantity of carbonic acid respired, so that alcohol must be decomposed in the body without any of the phenomena which accompany the decomposition of heat-givers. Dr. Richardson has further shown, in opposition to the generally received opinion, that there is a reduction of temperature in the advanced stage of alcoholic

poisoning from 98° to 96°; and that the narcotism of alcohol may be thus distinguished from the coma of apoplexy, in which there is a rise of temperature. It thus appears that a glass of hot brandy and water is a very poor protection against cold, and an equally poor remedy when a cold is contracted. The action of alcohol upon the blood-corpuscles is remarkable. These minute globules are slightly concave (Vol. I., p. 364), but it was discovered by Mr. Addison that, in contact with alcohol, they become changed in form by the withdrawal of water, and are aggregated into columns, or disposed in star-like groups. The result is that the flow of the blood is impeded in the minute circulation, and in many cases actual coagulation occurs. Under such circumstances, adequate nutrition is an impossibility; food is rejected because it cannot be assimilated, and general atrophy or wasting speedily follows. The existence of this atrophy is not contradicted by the apparent fattening which often accompanies it in the case of persons who consume much beer or spirits. The increased deposition of fat is probably due to the transformation of sugar, which such persons ought sedulously to avoid. The want of tone in the nerves indicated by the trembling limbs and shaking hands is one of the most distressing symptoms of alcoholic poisoning, for, as the nerves emanate from the brain, that organ participates in the mischief, and loss of memory, dimness of sight, drowsiness, dulness of perception, and, lastly, the fatal delirium which ends this "strange, eventful history," are so many signs of progressive cerebral disorder.

VOYAGES IN CLOUDLAND.

By T. C. Hepworth.

IF a bladder half-full of air, with its opening tied securely, be placed in front of a fire, or subjected to any other source of heat, it will rapidly become so fully distended that its sides will be tense and hard to the touch. If the bladder be completely filled with air, it will probably burst with a loud report very soon after the heat reaches its contents. We need hardly say that this effect is not due to any peculiar property possessed by the membrane, but is caused by the rapid expansion of the heated air contained within it. A little contrivance, which is used as a drop-bottle by oculists, illustrates the expansion of air by heat in a very forcible manner. It consists of a little glass globe furnished with a tube having a very small orifice (see Fig. 1). Liquid contained within the globe flows out drop by drop directly the little instrument is inclosed within the warm hand.

Fig. 1.—The Drop-Bottle.

It is clear that air in this expanded state must be lighter, bulk for bulk, than air at the normal temperature. It therefore—for the same reason that a cork will float on the surface of the water—rises in the denser atmosphere around it. It is said that the first inventors of the balloon—the brothers Montgolfier—were prompted to experiment by observing the smoke rising from the chimneys round about their home. They imagined that the ascensional power was due to some hidden property possessed by the smoke. They therefore argued that if they could but envelope enough of that vapour in a large bag, it would be able to float above the earth. They soon found that the heated air gave the motive power, and after a few trials the first balloon-ascent astonished the world. But ages before the Montgolfiers' time, men had turned their attention to the possibility of navigating the air, and history records many fatal attempts of enthusiasts, who, furnished with wings, have boldly plunged from high buildings into the yielding atmosphere.

Man in a savage state would soon learn how to support his body in water, and the accidental help afforded by a floating tree-trunk would give him the first notion of the use of a boat. From this small beginning he has so far conquered the seas as to cover them with ships, which resemble in their capacity floating villages. The land itself shows few places where man has not planted his foot, from the summit of the most lofty mountain, to the very bowels of the earth. But with regard to the air, he has made little or no progress. He sees birds and insects around him which are able to support themselves and travel in the air with great rapidity; but, do what he will, he cannot imitate

them. Indeed, the common phrase, "I can no more do such and such a thing than I can fly," is a tacit acknowledgment that such a means of locomotion is denied him. But, as we have already said, many have been convinced to the contrary, and have paid for their belief with their lives.

It is not a matter of much surprise that almost all the so-called "flying-machines" have been modelled from the form of wings with which birds and insects are furnished. This has been done without any reference to the immense disproportion which exists, weight for weight, between the muscular power of man, and that of his humble but more successful competitors. Let us take one instance. A common flea—alas! too common—will jump at one bound 200 times its own length. If a man possessed the same proportionate power, he would, standing on Ludgate Hill, be able to jump clean over the dome of St. Paul's Cathedral without putting forth his full strength. Could he accomplish such a leap, we may feel satisfied that the power could be utilised for putting in motion a pair of wings for his support in the air. But man is—compared with the lower creation—such a weakly thing, that any attempt to imitate the flight of a bird must end in failure. It is worthy of notice that in all such attempts a strange inconsistency appears. Enthusiasts have been so confident of success that they have placed their lives in jeopardy by invariably taking their flight from some high tower, or other eminence; whereas, were their wings worthy the name, an attempt from a table a few feet above the ground would have demonstrated their capabilities for flight equally well without any risk. The last victim in this country who perished in the attempt to fly, was De Groof, an engraving of whose machine we annex (Fig. 2). It was attached to a balloon which rose from Cremorne Gardens, in 1874. At a given signal, the frail apparatus was detached from the car, when it collapsed and fell heavily to the ground with its luckless contriver. Fig. 3 represents the flying apparatus designed by M. Leturr, whose invention also cost him his life.

The first flying-machine worthy of notice as bearing some resemblance to the modern balloon, was suggested in 1670, by a Jesuit named Francis Lana. It was to consist of a basket-work boat, having a mast and sail, and carrying at the ends of vertical rods four large spheres made of sheet-copper. These metallic receptacles were to be exhausted of air, which operation the inventor fondly hoped would cause the machine to rise from the ground. In theory his argument was perfectly correct, and if the balls had been made of some substance strong enough to resist the pressure of the atmosphere, and at the same time of extremely light weight, his wishes might have been realised. But he did not know, nor did any one at that time, that the atmosphere presses upon the air with a

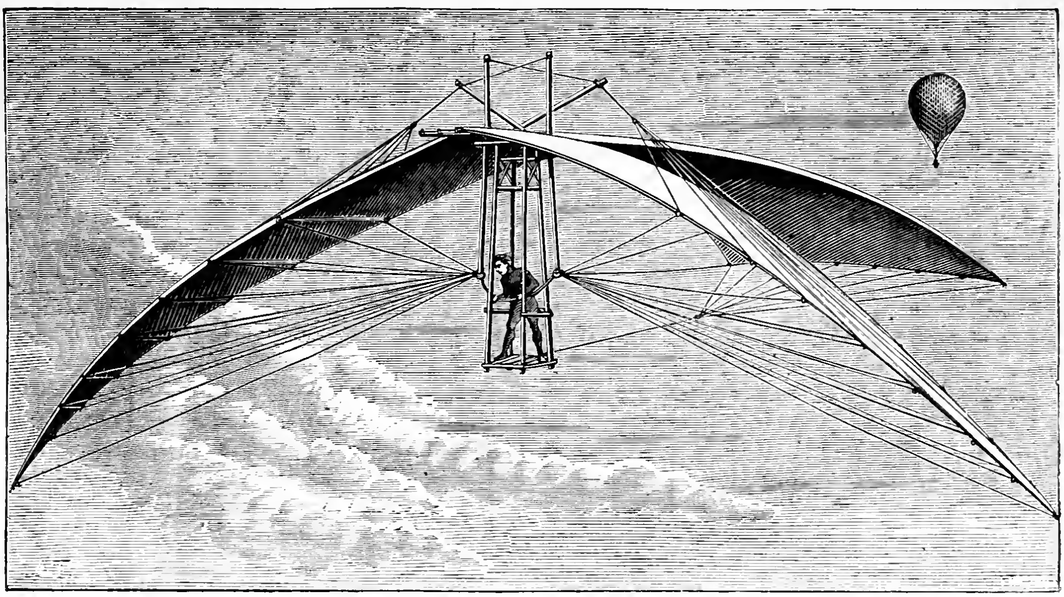

Fig. 2.—De Groof's Flying-Machine.

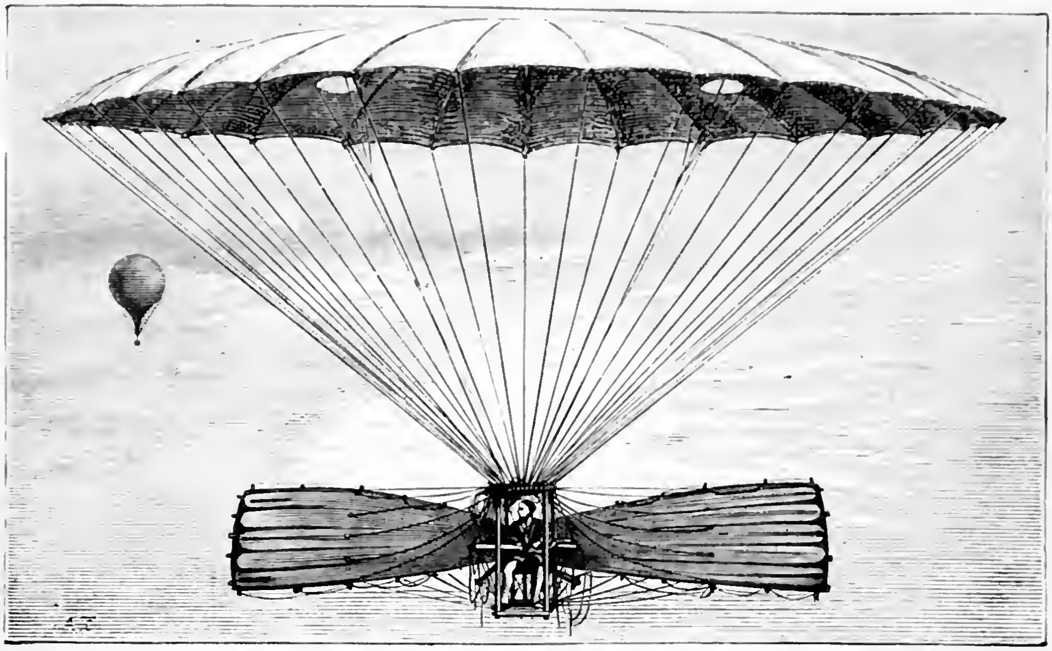

Fig. 3.—LETURR'S FLYING-MACHINE.

weight equal to 15 lb. on every square inch—a pressure which would of course have crumpled up the exhausted air-balls as if they had consisted of egg-shells rather than copper. One hundred years passed without any advance upon this impracticable but suggestive proposal of Lana's, when Cavendish startled the scientific world by his discovery of inflammable air, or, as we have learnt to call it, hydrogen. Dr. Black, of Edinburgh, at once pounced upon the new vapour as one which, on account of its extreme lightness, would enable bladders to rise in the air. Cavallo, in 1782, experimented in this direction. He found that a bladder was too heavy for the purpose, and that paper, by reason of its porous nature, would not hold the gas. But he inflated soap-bubbles with hydrogen, and saw them rise to the ceiling of his laboratory.

In the same year the brothers Montgolfier were carrying on their experiments at Annonay. Their first serviceable balloon—the outcome of various attempts—was made of linen and lined with paper. It measured nearly 40 feet in diameter, and weighed more than 400 lb. The necessary heat was obtained from burning straw, which was placed under a wide orifice left for that purpose in the lower part of the balloon. The excitement caused by the newfangled machine soon spread to Paris, where many scientific men turned their attention to the subject. Among them was M. Charles, who was led to experiment with hydrogen. He manufactured a small trial balloon of silk, which he covered with an elastic varnish, and he had the satisfaction of seeing it rise in the air, until it disappeared in the clouds.

Up to this time no man had had the courage to ascend, although different animals had been sent up, and had accomplished their aërial journey without accident. But in 1783, Rozier, with whom one of the Montgolfiers had now established a kind of partnership at Paris, was induced to enter the car of a balloon. The machine was attached to cords which permitted an elevation of only about 70 feet, but the experiment clearly showed that man had, to a certain limited extent, learnt how to support himself above the surface of the ground. A more daring flight was speedily announced, and Rozier, with an adventurous nobleman, were the aëronauts. The balloon used on this occasion held about 6,000 feet of hot air, which was supplied, as in Montgolfier's previous experiments, by a small furnace of burning straw. The balloon ascended to a considerable height, but in coming down the material of which it was made took fire, and the two occupants of the car narrowly escaped with their lives. Meanwhile, the advocates of hydrogen were not idle. MM. Charles and Robert opened a subscription to meet the expense of constructing a silk

balloon 26 feet in diameter. This balloon is worthy of notice as having furnished a model for most of those which followed it. An ascent to a great height was successfully accomplished, the aëronauts landing several miles from their starting-point. But the strange-looking monster so excited the fears of the ignorant peasantry, that in a few minutes after its descent they had torn it to shreds. Ballooning now became common throughout France and other countries, and some amount of rivalry existed between the supporters of the Montgolfier system and those who advocated the use of hydrogen. But it soon became evident that each method possessed special advantages of its own. The former was of course liable to danger from the furnace which it carried, but it was more under control than the gas-balloon, for by judicious use of the fuel it could be made to rise or fall as often as might be wished. The gas-balloon, on the other hand, could only be lowered by allowing its very life-blood to escape. Moreover, the operation of filling it in the first instance, was attended by much difficulty and expense. But M. Rozier, with another, determined to take advantage of both systems, by crossing the channel by means of twin balloons fastened one above the other. The upper balloon was filled with hydrogen, while the lower one by which the ascending power was to be regulated, was constructed on the Montgolfier system. It is not surprising that this foolhardy attempt to bring an inflammable gas into such close relationship with a furnace of flaming straw led to a disastrous result. The gas exploded, and the bodies of the two unfortunate men were hurled to the ground. These were the first victims of ballooning, and many have since perished in similar expeditions. But considering the large number of persons who have trusted themselves to the mercy of the winds in such frail vessels as balloons represent, the percentage of deaths recorded is very small.

In England numerous ascents have been made, but ballooning has in this country sunk to a mere means of amusement at public gardens and like places; although we must except certain expeditions presently to be noticed, which have been undertaken for scientific purposes. One of the most remarkable ascents on record was made from London in 1836, by Green, the well-known aëronaut. He landed with his companions the next day at Nassau, having travelled across sea and land a distance of 500 miles. The same veteran balloonist made altogether no less than 1,400 ascents. He suggested, among other improvements, the use of the guide-rope, which consisted of a long cable which trailed from the car. This contrivance was found particularly useful in crossing the ocean, where it steadied the balloon, and kept it at one constant altitude.

The extra risks attending the use of a fire-balloon are twofold. The first arises from the sparks—which may be obviated to a certain extent by soaking the balloon material in a solution of alum—and the second from the accumulation of unconsumed vapours in the body of the balloon, which may at any time explode. These and other considerations have led to the almost total abandonment of the Montgolfier balloon, in favour of that which is filled with gas.

A gas-balloon is simply a large bag, usually either spherical or pear-shaped, which is made of some material impervious to the vapour which it has to contain. The material generally found most suitable for moderate-sized balloons, is corah silk, covered with several layers of caoutchouc varnish. The entire machine is clothed in a network of strong cord, to which the car and its appendages are fastened. By this means an equal weight is distributed over each portion of the envelope, and no part of it is pulled out of shape. The network terminates below the balloon in a wooden hoop of several feet in diameter, and from this hoop depends the car. The latter, which is generally made of basket-work, is hung at some distance below the balloon, in order that its occupants may not be affected by the escape of the gas. At the top of the balloon is a valve which opens inwards, but closes with a spring. It is governed by a cord which passes through the body of the balloon, into the car beneath, so that it may be under the immediate control of the aëronaut.

The lower opening of the balloon, through which it receives its complement of gas, is left unclosed during an ascent. For as the machine rises, the air becomes less and less dense, and the gas naturally expands. In the early days of ballooning, many casualties happened through neglect of this precaution. The car is furnished with ballast in the form of sand-bags, which are emptied one by one at the discretion of the aëronaut, care being always taken to reserve as much as possible to check a too sudden descent. A great deal of judgment is in fact required both in the use of the ballast, and in the management of the escape-valve. By their aid, the operator can rise and fall until a certain limit is reached, when, the balloon being half-empty he must perforce return to mother earth. In descending, the half-inflated bag naturally takes an umbrella-like

or parachute form, and the force of the fall is thus considerably checked.

Although hydrogen gas is, on account of its lightness, the most suitable agent which can be employed for balloons, its preparation in a pure form is attended by much expense and many difficulties in the way of apparatus. For these reasons carburetted hydrogen—that is, common coal-gas—is much more frequently adopted for the purpose. It is much heavier than pure hydrogen, but this fault is counterbalanced by the ease with which it can be obtained. The first product of the retorts is richer in carbon than that portion which subsequently comes away, and is therefore more valuable for illumination. But the latter portion is far lighter, and more nearly approaches pure hydrogen in its properties. Balloonists generally arrange with the gas company with which they deal, to be supplied with this special kind of gas. The aëronaut Green was the first to employ coal-gas for balloons.

Perhaps no contrivance has ever led to such preposterous suggestions as the balloon. It is not altogether surprising that the ancients should imagine that the upper limit of our atmosphere presented a definite surface like the ocean, and that if this could once be reached, aërial navigation would become an established art. The discovery of the barometer of course negatived such an idea. But this is as nothing compared with the notions which, shortly after the first balloon-ascents, occupied the minds of those whose imaginations outran their scientific attainments. One would-be inventor gravely suggested that a flock of birds should be harnessed to the car, and he was good enough to point out that eagles or falcons would be the most eligible birds for the purpose. Geese, we should imagine, might have done equally well. Another inventor, named Campenas, was also troubled with aërostation on the brain. He did not divulge his plans further than to propose to Bonaparte, in 1796, the construction of an aërial ship, which was to hold 200 persons, and which could be directed to every point of the compass. In his address to the Emperor he writes: "I myself will be your pilot. You can thus, without any danger, hover above the fleets of enemies jealous of our happiness, and thunder against them like a new Jupiter, merely by throwing perpendicularly downwards firebands made of a substance which will kindle only by the contact and percussion at the end of its fall, but which it will be impossible to extinguish. Or, perhaps you will think it more prudent to begin at once by forcing the British Cabinet to capitulate; which you may easily do, as you have it in your power to set fire to the City of London, or to any of the maritime towns of England." He goes on to say that the projected machine will be capable of travelling from Paris to London, destroying the latter city, and returning to Paris all within twenty-four hours. A truly modest programme!

But within far more recent years, schemes quite as impracticable have been mooted with equal confidence on the part of their projectors. No later than July, 1835, an aërial ship was advertised to sail from London to the different European capitals. It was depicted on the advertisement-bills as a barrel-shaped balloon, 160 feet long by 40 feet in diameter, and capable of carrying 17 passengers. We need hardly say that this curious ship never sailed.

It is evident that all these wild projects depend upon some fancied notion of being able to steer a balloon, irrespective of the power of the wind to blow it in one direction. Most of them consist of an arrangement of fans and vanes to be set in motion, and to act upon the air much in the same way that the screw of a steamship repels the water. Indeed, the favourite argument peeps out here that, because water is navigable, air, too, can be brought under subjection. A little thought will show how dissimilar the two cases really are, one being an elastic fluid, and the other inelastic. If we put a buoyant thing, such as a boat, into water, there it is supported on the surface. We have no further trouble with regard to its floating capabilities, so that we can give our sole attention to propelling it. This we do by the aid of another power—namely, the force of the wind. We therefore have two different servants in our employment—one being the water which bears our vessel up, and the other the wind which pushes it forward.

But in ballooning we have but one medium to which we can trust our frail bark—a medium which surrounds it on all sides. Besides this, our vessel must be of an unwieldy size to enable it to float at all. When once launched, it takes all our pains to prevent it rising too high or sinking too low. We can thus rise or fall in the air to a limited extent, but beyond this we can do nothing. The wind which, in the case of a water-boat, can by means of sails be made to do our bidding, is now our master, to drag us with him whichever way he may happen to be going. The huge surface which a balloon necessarily presents to his influence, gives him an enormous control over it. In short, it would be as impossible for us to stem the current

of air, as it would be for some little beetle that had fallen into a river to attempt to swim against the force which hurries it down stream.

Every kind of motive power has been at some time or other suggested for application to ballooning. Compressed air will seem to one inventor the most suitable for the purpose; another will propose steam; both forgetful that the weight of either air or steam engine would necessitate enormous gas-envelopes. Then comes the electrician; but the force with which he deals is, as a motor, so far as our knowledge at present extends, simply useless for anything but the lightest work. Carbonic dioxide is next proposed, and we are to sail through the air by means of enlarged seidlitz powders. In order to show the utter absurdity of all these projects for battling with the wind, let us imagine for one moment that a motive power and suitable engine have been found, and have been placed in the car of a balloon. We will suppose that an easterly wind is blowing, while the course we wish to travel lies due east. Let us now watch the result. The engine is set in motion, and it is so powerful that the balloon is dragged behind the car, the cords to which the latter is suspended assuming a horizontal position. The huge balloon staggers in the rear like an ill-made kite. The aëronaut is at last tempted to exclaim—"Of what use is this cumbrous bag of gas? let us cut it adrift and fly without it." In other words, an engine that could exert sufficient force to pull a balloon against the wind could easily be made to rise from the ground of itself. The balloon would therefore be useless. An indiarubber toy balloon, tied by a short string to the finger, and moved against a moderate breeze, will quickly assume a horizontal position. But the difficulty is perhaps better illustrated by a small child who endeavours on a windy day to cope with the vagaries of a large umbrella. Before dismissing this part of our subject, we may mention the possibility of turning a balloon round by means of vanes, but beyond this nothing can be done. In fact, so far as controlling the movements of the machine, we are in precisely the same position as were the Montgolfiers when their paper bag first rose into the sky.

The only hope that remains to us of being able to steer balloons to pre-arranged havens, lies in the possibility of there being, at certain elevations in the atmosphere, currents of air having a definite velocity and direction. Many have supposed that this is the case, but the probabilities of such a notion being true are most vague. A Dr. Van Heche was the first to propound the theory, and he proposed by screw vanes to rise and fall in the air until the particular current was hit upon which agreed in its direction with the course he wished his balloon to steer. The aëronaut Wise, of New York, was so satisfied with the soundness of this doctrine of constant currents, that he resolved (in 1873) to cross the Atlantic. An immense balloon was constructed for the purpose, but owing to the bad quality of the materials, it split up in all directions directly the gas distended its sides. The scheme collapsed with the balloon, which was perhaps a lucky circumstance for the intended passengers.

The science of aërostation has by no means suffered for want of daring schemes involving apparatus of enormous size. In 1863, a balloon called *Le Géant*, containing 200,000 feet of gas, was constructed at Paris. The car consisted of a small cottage residence of two storeys, with every appliance to make it comfortable and homelike. It numbered among its conveniences a refreshment-room and a lavatory. Thirteen passengers were carried at its first ascent, but the journey lasted only four hours, owing to some accident to the valve-line. The second and final ascent came to rather a disastrous termination after a flight of seventeen hours. For the balloon descended during a high wind, which dragged the cottage and its occupants bumping along the ground for several miles. The passengers were, of course, much hurt, and it is questionable whether there was one among them who ever again trusted himself so far above his native earth. This balloon and its somewhat shattered car were subsequently exhibited at the Crystal Palace.

The next large balloon-car constructed was a Montgolfier, which made two ascents from London in 1864, both of which were witnessed by the writer. This balloon had a capacity of half a million cubic feet. The car was merely an annular gallery round an iron stove in which compressed straw was burnt. Bundles of this fuel were suspended from the car. The aspect of the roaring flames mounting high into the wide opening of the balloon, as it rose majestically in the air, formed a very startling and impressive sight. This balloon, or one very similar to it, was later on completely consumed in the grounds of the Crystal Palace just before a contemplated ascent.

Scientific men soon saw that the balloon afforded them a means of examining the higher strata of the atmosphere, and of obtaining information which it

was almost impossible to procure by other expedients, and at the beginning of the present century many ascents were made in different countries for the purposes of science. M. Sacharof, of St. Petersburg, turned his attention to acoustical phenomena, and, among other results, he obtained, by means of a speaking-trumpet, a distinct echo from the surface of the earth while he was sailing a mile and a half above it. Gay-Lussac and Biot endeavoured to detect variations in the magnetic phenomena of the earth in the higher regions of the atmosphere, but without success. They also brought down bottles of air from different altitudes, which on examination proved to be normal in its proportions of oxygen and nitrogen. In 1852, Mr. Green, in the Nassau balloon, made four ascents from the Kew Observatory, and recorded similar results. But perhaps the most important service in this direction was rendered ten years later, by Mr. Glaisher, who, on behalf of the British Association, undertook a series of ascents in company with the well-known balloonist Coxwell. The highest ascent ever recorded was accomplished by them on September 5, 1862.

The balloon left Wolverhampton on that day at 1 o'clock P.M., the temperature being 59°. At the height of one mile the thermometer registered 41°. At this height they entered a cloud, the estimated thickness of which was 1,100 feet. Leaving this cloud, they suddenly burst into a sunlit expanse,—the clear blue sky above and an ocean of clouds below, which formed hills and vales, and mountain chains, while the sunlight gave the whole scene an appearance of the most sublime beauty. They threw out more ballast, and rose until the barometer told them that they were five miles above the ground. Here Mr. Glaisher's sight began to fail him, and he had great difficulty in recording the observations which up to this time had engrossed his attention. His limbs soon became motionless, and in a few minutes he fell back insensible. His companion was affected in almost as great a degree, for he lost the use of his hands, which appear to have turned black. He had, however, sufficient strength to pull the valve-cord with his teeth, and the descent, of course, commenced. The height reached on this occasion was no less than seven miles, and from the effect produced on the occupants of the car, we may consider this the extreme limit to which man can go without losing his life.

Many useful observations were made during Mr. Glaisher's ascents. They chiefly related to humidity and temperature; but others of a physiological character, such as the effect of the rarefied air upon the pulse and the inspiration of the lungs, were also recorded. Some pigeons which were taken up dropped down like stones when they were released from the car, and only one of their number again reached Wolverhampton. At the higher elevations an absolute silence reigned, but at two miles the bark of a dog was heard, and at four miles the noise of a railway-train was detected.

The marvellous effects of light and shadow which are often observed from a balloon, no pen can describe; while occasionally optical phenomena of a more extraordinary kind may be witnessed. In describing one of his ascents, M. Charles writes:—"When I left the earth, the sun had set on the valleys; *he now rose for me alone.* Presently he disappeared, so I had the pleasure of seeing him set twice on the same day." We annex as illustrations a view of Cloudland (Fig. 4), and a lunar halo (Fig. 5), as seen during an ascent.

Beyond the scientific questions which balloons have enabled us to answer, they have of late years been found most useful adjuncts to military expeditions. And there is little doubt that in the future—we fear that there *is* a future for the horrors of war—their use will be still further extended. In the French army they were used so long ago as 1794, and again at Solferino; while during the late struggle with Germany they were so commonly employed, that Herr Krupp was called upon to devise a special form of long-barrelled, pivoted gun with which to take pot shots at them. But bullets have little effect in stopping the progress of a balloon, for a rent in the material far larger than a bullet would cause, would do little more than act as a safety-valve for the gas.

During the siege of Paris no less than sixty-four balloons started from the ill-fated city. Two of these were carried sea-wards, and were never afterwards heard of, several fell into the hands of the Prussians, and the rest escaped to friendly territory. We notice in the French Budget for 1877, a credit of 200,000 francs was allowed for military ballooning. This fact alone will show that our neighbours are far from thinking lightly of the matter. But its consideration is not confined to the French, for during the American war a regular staff of balloonists was attached to the Federal army. And even the Japanese have constructed an immense balloon for the same kind of service.

Our own War Department is not blind to the advantages which the use of a balloon will often afford, and some experiments have been carried on at

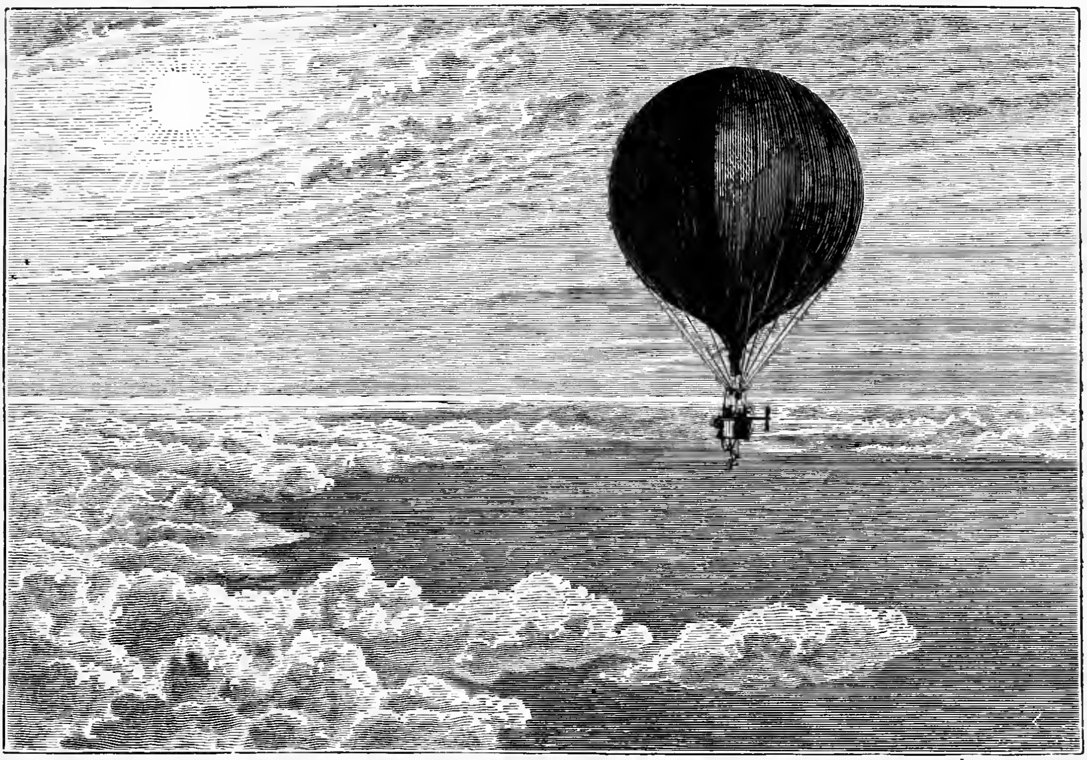

Fig. 4.—Above the Clouds.

Woolwich with the object of obtaining some definite information regarding its performance in the field. These seem to have consisted principally in determining the smallest amount of hydrogen which will raise a man from the ground; and also, by careful study of the direction of the wind and of the map, to calculate the spot which a balloon will reach in a given period of time. It may perhaps be as well to add that these experiments have been carried on under the auspices of a select committee of the War Department. In this connection we may mention that a means has been found of procuring maps by the help of a small captive balloon carrying a photographic camera. The camera is furnished in the usual way with a sensitive plate, which is exposed for the fraction of a second by the action of an electro-magnet. In this way a correct picture of an enemy's works can be obtained, showing the number of guns mounted, and the various details of the defence. Two other uses have also been suggested for small balloons. The first, that of determining the height of clouds by calculating the time which elapses before they disappear, and so obtaining data on which to found weather predictions; while the other proposal consists in the employment of balloons to establish communication between a sinking ship and the shore. But the latter notion evidently came from a theorist who never tried the experiment of handling a gas-bag in a gale of wind.

With the exceptions noticed in connection with scientific aims, and military service, modern ballooning seems to have resolved itself into a means of obtaining bird's-eye views for the gratification of holiday folk. The first captive balloon of this public nature was instituted at the Paris Exhibition of 1867. Its diameter was 93 feet, and it had a capacity of no less than 421,000 cubic feet. The gas used was pure hydrogen. The car held twenty-five persons at each ascent, and a rope was attached to a drum, which revolved by steam-power. Another balloon, slightly larger, but similar in construction, was established at Chelsea, in 1869. The material used in making these balloons was a kind of compound cloth, consisting of indiarubber and canvas. The drum on which the cable of 2,000 feet was wound, measured 23 feet in length, and had a diameter of $6\frac{1}{2}$ feet. Two engines of 150 horse-power were employed to haul the machine to the ground. The view obtained from this balloon was,

when the smoke of London permitted, very fine, for the windings of the Thames could sometimes be traced from Berkshire to Greenwich. But for some unknown reason, the Londoners did not patronise the show, and the speculation was an utter failure. In the sequel, this balloon escaped from its moorings, but its cable acted both as a guide-rope and an anchor, and it was recovered afterwards some miles from town.

The largest balloon ever made formed one of the chief attractions of the 1878 exhibition at Paris. It was constructed by M. Henry Giffard, the designer of the balloon already mentioned which ascended from the Champ de Mars in 1867. It forms a perfect sphere of nearly 120 feet in diameter. The material used is a compound cloth, consisting of layers of muslin, indiarubber, and canvas, all firmly adhering together, so as to form a compact gas-proof skin. The exterior is painted white, both for the sake of preservation, and to prevent the gas within becoming unduly heated by the sun. The balloon carries fifty passengers and two aëronauts, and the total weight which it raises is no less than 22 tons.

The car is ring-shaped, and has an external diameter of 19 feet, the annular floor being a trifle over a yard in width. As in the previous captive balloons mentioned, the rope diminishes in diameter as it reaches the earth, so that if it accidentally gives way, it will do so at its weakest part, and the major part of it will remain attached to the balloon. This cable is made of hemp. One of steel was suggested, but fears were entertained that it might form a tempting path for atmospheric electricity, to the danger of the passengers.

The winding-drum consists of a hollow cylinder, 33 feet long, connected with two powerful steam-engines. As the rope is paid out, these engines are so contrived that they act as air-pumps to feed a pneumatic brake. This brake so checks the balloon in its ascent, that when the limit of the cable is reached, the huge machine is brought to a standstill without any jerk or inconvenience to the passengers. The amount of work which the construction of this balloon entailed may be judged from the fact that the mere sewing of the seams employed 100 girls for one month. The cordage, the cable, and the strength of the various materials used, each formed a matter of serious study and calculation. Indeed, we may say that in this balloon the science of aërostation, so far as it can be represented by a captive machine, has been brought to the greatest pitch of perfection.

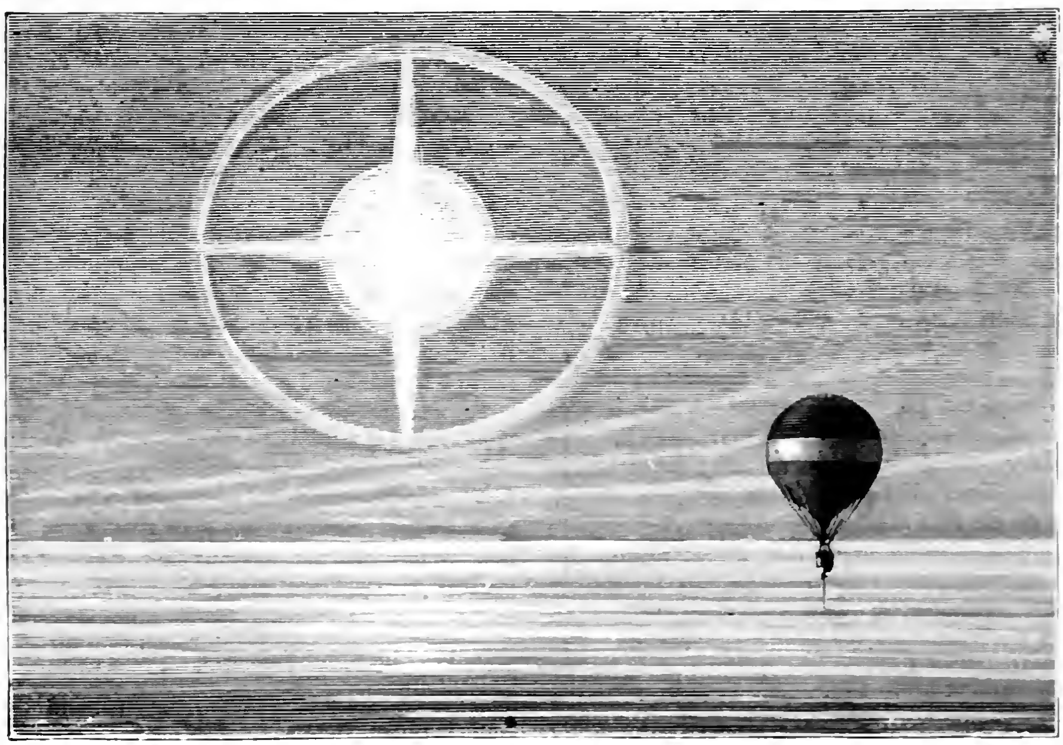

Fig. 5. A Lunar Halo.

It will be seen from the foregoing remarks that the problem of aërial navigation has yet to be solved. Indeed, it is a question whether man will ever get nearer the consummation of his hopes in this direction than he is at present. But science makes such rapid strides, that we dare not say that this generation will not see the wish fulfilled. The consideration of the many difficulties which surround the subject will perhaps teach us as well as anything the littleness of man's hopes and aspirations. The knowledge which is permitted him, outruns in a manner his power of profiting by it. The telescope teaches him that the world on which he lives is a very small planet compared with others in the same system. It also shows him distant spheres which form parts of other systems, so exceedingly remote that he is perfectly unable to arrive at any conception of their distance. The nearer worlds which are in comparison so close to him, and which form planets revolving round the same sun which warms this earth, he knows to possess atmospheric phenomena. He concludes from all these things, that men like himself have their being there. But between him and them there is an everlasting barrier—a barrier which consists of emptiness, but one so strong, by reason of its absence of that air which is necessary to life, that it might as well be a wall of molten iron. He can look beyond that wall for millions and millions of miles, he can even tell the constituents of the stars he sees there, but he cannot tread one step into that great unknown which he vaguely calls space.

THE CHEMISTRY OF WATER.

By J. Falconer King, F.C.S.,

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THE "elements," according to the ancient philosophers and the early cultivators of science, were four in number—namely, air, fire, earth, and water. This opinion, which was shared by the great majority of, if not by all, scientific men during the first half of last century, has been proved by modern scientific research to be very erroneous; and yet, in consequence apparently of the length of time during which the dictum of these fathers of chemistry on this subject was accepted without dispute, and with all but universal credence, it is by no means uncommon even in the present day to hear of what is supposed to be signified by these four words—air, fire, earth, and water—referred to as "the four elements." Elements, however, they are not—at least in the modern acceptation of the word. What we in the present day designate an element is a substance which, so far as we are able to demonstrate, consists of but one kind of matter only. Now air, by which we understand atmospheric air, and earth, far from being elements, are composed, it need hardly be said, of several different substances, some of which are elementary and some compound. Fire is neither more nor less than the phenomenon caused by matter in a state of combustion; and water, with which we are more immediately concerned at present, is a true and well-defined compound, consisting of two perfectly distinct kinds of matter.

Water was declared to be an element by Aristotle, but it is right to remember, in giving him credit for this, that the word element in his day did not possess exactly the same significance that it does in the present. An element, however, he called it, and so it was regarded until the year 1781, when the distinguished English chemist, Henry Cavendish, fully and conclusively demonstrated its compound nature. This Cavendish succeeded in doing by means of the chemical process known as synthesis.

Chemists are acquainted with two modes of investigation, whereby they are enabled to determine the composition of compound substances. These two modes are called *synthesis* and *analysis,* and consist, as their names indicate, of a putting together and a taking asunder.

To prove the composition of a substance by analysis, we take it to pieces, and show that it is a compound by producing each of its several constituents in a separate state. By the process of synthesis, on the other hand, we prove the same thing by putting together the different ingredients, and so producing a whole. Thus, we might show the composition of a watch, either by taking it asunder and producing the wheels, pinions, hands, dial, &c., each in a separate state; or by putting these different constituents properly together, thereby manufacturing, so far, the complete machine. In each case we should have satisfactorily shown that a

watch consists of the different pieces named. We should in both instances have proved the same thing—viz., the composition of the watch—but by two different processes.

The taking of the watch to pieces represents the process of analysis; while the other operation, that of producing the compound machine by bringing the different parts together, illustrates that which we call synthesis.

The compound nature of water can be very satisfactorily proved by means of either of these processes; but as it was by the process of synthesis that this was first done by Cavendish, this mode of showing its composition has always a peculiar interest for us, and shall therefore be first described.

Water, as we have learned from the results of the experiments of Cavendish, consists of the two elementary substances—hydrogen and oxygen—or, as he called them, inflammable air and dephlogisticated air. These two substances under all ordinary circumstances are gases, and when perfectly pure they are colourless, tasteless, and inodorous. The former —hydrogen—is exceedingly light; it is much lighter than atmospheric air, and is, indeed, the lightest form of matter with which we are acquainted. Oxygen, on the other hand, is comparatively heavy, a given quantity of it weighing no less than sixteen times as much as an equal volume of hydrogen. How to make these gases, as well as some of the more marked properties of each, has already been explained (Vol. I., p. 283). The most marked properties, however, of hydrogen and oxygen are shown when they are brought in contact with a lighted match. Hydrogen in such circumstances at once catches fire, while the burning match, if plunged into the gas, is immediately extinguished, which shows that this gas, though readily inflammable, is not a supporter of combustion—that is to say, it will burn with facility itself, but will not maintain the combustion of other substances. Oxygen, on the other hand, is not inflammable, but it is a supporter of combustion; it will not burn itself, but it promotes in an eminent degree the combustion of bodies which are inflammable.

Water has been chemically examined many times since Cavendish made his famous experiment, and these examinations, when properly conducted, have always yielded substantially the same results as those which he obtained, both as regards the different kinds of matter which enter into the composition of water, and the proportions in which these are present. For it has not only been proved that water always consists of the two gases just named, but it has been shown most conclusively that the proportions in which they are present are invariably the same. In 9 lb. of water we always find 1 lb. of hydrogen and 8 lb. of oxygen; or if we measure the gases instead of weighing them, we always find two volumes of hydrogen united with one volume of oxygen.

If, therefore, we take, let us say, two pints of hydrogen and one pint of oxygen, and mix them, and to the mixture apply a lighted taper, we shall at once cause the gases to "combine." They will enter into chemical companionship with explosive violence, all traces of them will disappear, and we shall have left in their stead, as the sole result of their union, nothing more than a few drops of pure water. In this way we prove the composition of water synthetically. We start merely with pure hydrogen and pure oxygen, we cause these to combine, and we obtain nothing more than pure water, demonstrating thereby that water is composed solely of these two substances. In Fig. 1 is shown a very simple piece of apparatus by means of which the composition of water may be proved by synthesis. A B is a strong glass tube closed securely at the upper end and open at the lower. It stands in a small trough, the bottom of which is covered about an inch deep with mercury. In the usual fashion this tube is filled with a mixture of hydrogen and oxygen gases in the proportions already mentioned. It is then arranged in the mercury trough in the manner shown in the drawing, and the open end being securely closed by being firmly pressed against a piece of indiarubber which lies on the bottom of the trough, the mixture in the tube is fired by the agency of an electric spark passed into the interior of the tube by means of the two wires which pass through its sides near the closed end. When the explosion has taken place, the lower end of the tube is slightly raised from the indiarubber cushion, when the mercury will immediately rise in the tube, filling it almost completely, thereby showing that a partial vacuum has been formed. This vacuum being produced proves that the gases which previously filled the tube have disappeared, and as there is nothing left in their place save a drop or two of water, we conclude that they have lost, by the chemical action which has taken place, their individual existence, and become converted into the compound which remains as the sole product of the change.

By this experiment we prove not only that hydrogen and oxygen are the sole constituents of water, but we show, seeing that the entire quantity

of each gas which we used was consumed, that the proportions of these gases existing in water must

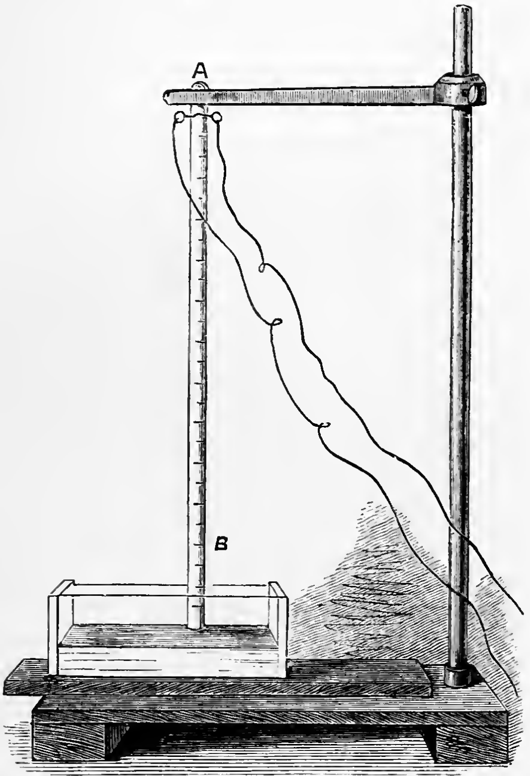

Fig. 1.—Apparatus for proving the Composition of Water by Synthesis.

be those which we employed--viz., two volumes of hydrogen to one of oxygen. If, for example, we had introduced two volumes of oxygen and one volume of hydrogen, or, in short, if we had taken any other proportions than those which we did employ, the whole of the gas would not have been consumed. This would have been shown after the combination had taken place by the mercury then occupying only a part of the tube instead of the whole, the remainder being filled by whichever gas had been used in excess. Thus if we had used equal volumes of the two gases, only half of the oxygen would have been consumed; the other half would have remained unchanged in the tube. And so we come to the conclusion, from the result of this synthetical experiment, that water is composed of hydrogen and oxygen in the proportion of two volumes of the former to one of the latter.

In Fig. 2 we have a representation of another form of apparatus which may be used to illustrate the composition of water. In the bottle A is a mixture of zinc, water, and sulphuric acid, three substances which when they are brought in contact generate hydrogen. The gas as it is produced is led by the exit tube B into the vessel C, which latter is filled with fragments of quicklime placed there for the purpose of drying the gas, which, after it has undergone this operation, issues at the exit tube D, when on being lighted it will burn with its characteristic non-luminous, pale blue flame. If this flame be then covered with a cold vessel in the manner shown in the figure, the water which is produced by the burning of the hydrogen, or, in other words, by the union of the hydrogen with the oxygen which is always present in the air, will be condensed, and may be collected for subsequent examination by placing another vessel to receive the drops as they fall from the edge of the inverted jar.

Having thus seen how the composition of water may be proved synthetically or by putting together its constituents, it now remains for us to show how its composition may be demonstrated by the converse process of analysis. There are various methods by which water may be analysed or resolved into its component parts. The simplest of these is that in which we employ the power of electricity. To effect the analysis of water by this agent we employ the apparatus shown in Fig. 3, which consists essentially of a glass vessel A, through the sides of which are passed two wires terminating inside the vessel in platinum plates and communicating externally with the opposite poles of a

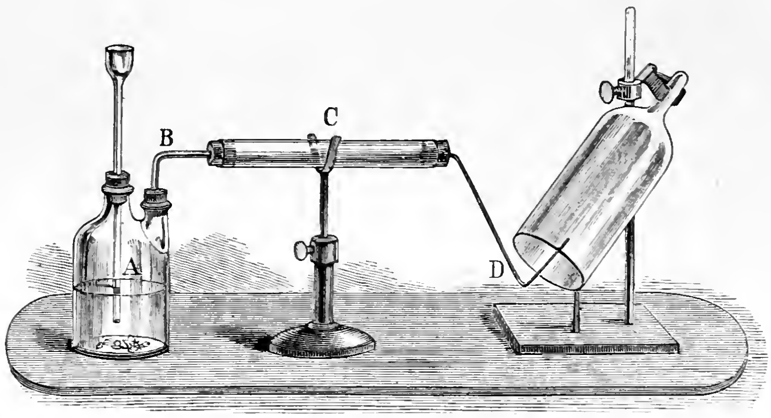

Fig. 2.—Another Apparatus for showing the Composition of Water by Synthesis.

galvanic battery (Vol. I., p. 46). The vessel A having been filled with water, to which a little sulphuric acid has been added merely for the purpose of allowing a freer passage to the electricity, and the battery having been set in action, bubbles of gas will at once be given off, apparently from the two platinum plates. If two tubes filled with water be now inverted over the plates of platinum in the manner shown in the drawing, the bubbles of gas instead of escaping into the air will rise into the tubes, displacing the water as they do so, and speedily fill them. On examining the gas so produced by applying a lighted match to the mouth of the tube containing it, it will be found that while the gas in one of the tubes is of a highly inflammable nature, that in the other will not itself inflame, but will cause the match to burn much more rapidly. Thus while the gas in one tube extinguishes the lighted match and catches fire itself, the gas in the other promotes the combustion of the match, but shows no inclination on its own part to ignite. These, we know, are the distinguishing properties of the two gases hydrogen and oxygen, so that by this experiment we have proved analytically that water is composed of these two substances.

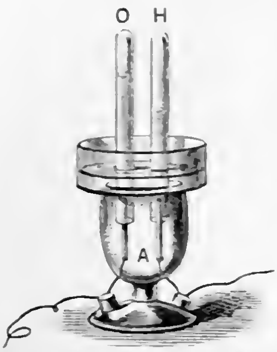

Fig. 3.—Apparatus for decomposing Water by Electricity.

If the current of electricity from the battery were continued long enough, the whole of the water would in time be decomposed, and we should have nothing left save the hydrogen and oxygen, a fact which proves positively that these gases alone are the components of water.

By close inspection of the tubes marked H and O in Fig. 3, it will be seen that the amount of gas in the H or hydrogen tube is twice as great as that in the oxygen tube. This result is strictly confirmatory of that which we obtained by synthesis, for it will be remembered that when we produced water by causing its constituents to combine, we required always to employ twice as much hydrogen as oxygen. By carrying our analytical experiment, however, a stage further, we can have additional proof of the accuracy of our previous results; and this we do by arresting the action of the battery when the hydrogen tube has just been filled, at which point we know the oxygen tube will only be half filled. Having thus procured two volumes of hydrogen and one volume of oxygen as the result of the decomposition of the water, we transfer both gases in the proportions in which we have received them to the strong glass tube used in the first experiment, and repeating that experiment by passing an electric spark into the mixture, we determine the union of the gases, and so reproduce the water which we have just decomposed.

Water may be analysed or decomposed in many other ways. By the action of the metal potassium, for instance, at ordinary temperatures, or by iron at a red heat, water is at once resolved into its constituents, the hydrogen being given off in the free state and the oxygen being seized by the metal. In Fig. 4 an apparatus is shown, by means of which water may be decomposed by the action of red-hot iron. To the extreme left is placed a retort containing water which is made to boil by means of the lamp placed beneath it. The steam thus produced is conducted by the exit-tube leading from the flask into a gun-barrel filled with iron turnings, which, with its contents, is maintained at a red heat by the little furnace F through which it passes. To the right end of the gun-barrel is fitted an exit-tube for the purpose of allowing the gas generated to escape. The apparatus being thus prepared, the gun-barrel is heated to redness, and the water in the retort is boiled. The steam arising from the boiling water is forced into the hot iron tube, where, by the action of the heated metal, it is at once decomposed. The oxygen, as already explained, is retained by the iron, and a new compound oxide of iron is produced, while the hydrogen, being thus separated from its companion, passes on

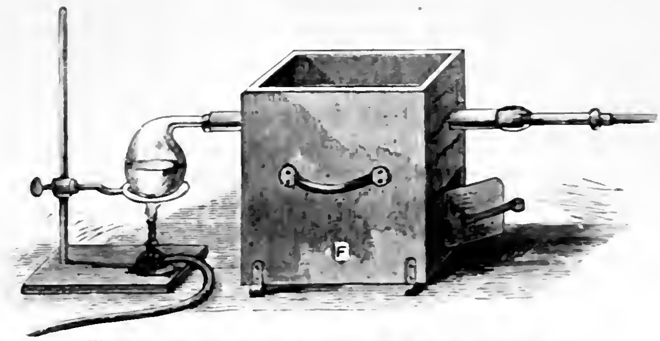

Fig. 4.—Apparatus for decomposing Water by Red-hot Iron.

through the exit-tube, at the extremity of which it may be ignited, and the water which it produces in the process of burning collected for examination in the mode shown in Fig. 2.

We have thus fully proved, both by synthesis and analysis, that water is not an elementary substance, but is a true and well-defined chemical compound, consisting invariably of the two gases, hydrogen and oxygen, in the proportion of two parts by measure of the former to one of the latter.

In considering the properties of water, one circumstance specially arrests our attention: that is, its perfectly neutral character. It has no taste, no smell, and almost no colour; it is neither acid nor alkaline, and when quite pure it is perfectly bright and transparent. It evaporates at all temperatures, and under the ordinary pressure of the air it boils at 212° Fahr. The boiling-point, however, is very much influenced by pressure, as has

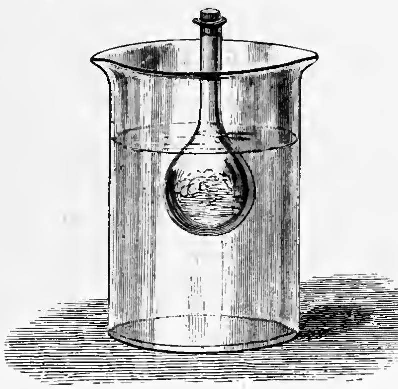

Fig. 5.—Water made to Boil by the Application of Cold.

already been discussed in previous articles (Vol. I., pp. 30, 70).

A simple mode of showing the effect of the pressure of the air in influencing the boiling-point, is to place some boiling water in a flask, the mouth of which is capable of being securely closed. In a few seconds after the flask has thus been made air-tight, the water will become quite quiescent, and if, when it is in this condition, the flask and contents be suddenly cooled, the latter, in consequence of the diminution of pressure caused by the condensation of the steam, will immediately begin to boil. A convenient mode of carrying out this seemingly paradoxical experiment is shown in Fig. 5.

When water is heated in close vessels, the tension or elastic power of the vapour or steam which is thereby generated becomes enormous. The Marquis of Worcester burst cannons by its power; and, as every one unfortunately is but too well aware, the strongest steam boilers are occasionally ruptured by the same force.

It is, indeed, to this force exerted by water-vapour that we are indebted for all the benefits we derive from the labours of the steam-engine. When water is converted into gas—or steam, as it is sometimes called—it expands to no less than 1,650 times its original volume, and in this fact we have an explanation of the great force which is generated when water is made to boil, or assume the gaseous state in closed vessels (Vol. I., p. 104).

Water, in common with some other liquids, can, by being heated strongly and suddenly, be made to assume a peculiar condition, in which, though warm, it never reaches the boiling-point. We can bring water into this spheroidal state, as it has been called, most simply by allowing a drop or two to fall into a red-hot metallic basin. The water, when it comes in contact with the hot metal, instead of boiling violently and disappearing almost instantaneously, as we would naturally expect it to do, collects in the form of a sphere, and moves over the heated surface without appearing at first to evaporate at all.

Indeed, although apparently resting on and surrounded by red-hot metal, the globule of water remains comparatively cold; it does not even approach the boiling-point, and it can by a little dexterity be easily touched by the finger, without any great feeling of pain being experienced.

When water is in this spheroidal state, although it does not boil, it evaporates quite distinctly; and although this evaporation proceeds very slowly, it will continue, if a sufficiently high temperature is maintained, until the water is entirely dissipated. If the temperature, however, is allowed to fall, the water at a certain point will enter into a state of violent ebullition, and will almost instantaneously be wholly converted into steam.

The explanation of this curious behaviour of water is very simple. At the exceedingly high temperature to which it is suddenly exposed, a small portion of it is instantly changed into vapour, which, as it is generated and exists between the heated metal and the water, acts as a screen or shield, and prevents the water from coming into immediate contact with the red-hot surface.

The water, in fact, does not touch the metal at all on which it appears to lie, but is separated as truly and completely from it as if some non-conducting material, such as a piece of incombustible cloth, were interposed between them. And so long as the hot surface is maintained at a temperature

sufficiently high to provide the necessary amount of the non-conducting vapour screen, so long will the water remain in the comparatively cold spheroidal state. If, however, the temperature be allowed to fall, and thereby the necessary supply of this protecting screen be cut off, the water will come in actual contact with the heated metal, and will then be almost instantaneously converted into steam.

Keeping in remembrance this curious property of water, many of the performances of the fire-eating magicians, which appeared to us so wondrous in our younger days, dwindle into mere commonplace tricks. All that is required to enable one to lick, handle, or tread upon a piece of red-hot iron is a little dexterity, and the careful wetting of the tongue, hand, or foot before commencing the experiment. When we place our wet hand on red-hot iron, the water, or part of it, is immediately converted into vapour, which acts as a shield and protects the skin from being burned by preventing it from coming into real contact with the heated metal. The escape of many persons from the ordinary effects of the fiery ordeal in olden times is no doubt also ascribable to the same cause.

Other liquids besides water can be made to assume the spheroidal state, and as liquids in this condition are always colder than they are when at their boiling-point, it follows that if we cause a liquid whose boiling-point is very low to assume this condition, we shall have thereby an exceedingly low temperature produced. Indeed, by a simple arrangement, the description of which, however, does not come within the scope of this paper, it is quite possible in this way in the course of a few seconds to produce sufficient cold to freeze water, and that while it is contained in a red-hot vessel.

We have already seen that one effect of the application of heat to water is, by converting it into gas, to cause it to expand enormously. When in the liquid state, water also expands under the influence of heat, though not nearly to the same extent. This being the result of the action of heat upon water, it is a very natural conclusion to come to that the application of cold would have an exactly opposite effect. And to a limited extent this conclusion would be quite correct, for until it is cooled to a certain point water does expand by heat and contract by cold. Beyond this point, however, it no longer follows the general rule, and instead of expanding by heat and contracting by cold, as almost every other substance does, it takes the very opposite course, and contracts by heat and expands by cold. If water at the ordinary temperature of the air be cooled it will contract, in obedience to the general law, and it will continue to do so as the temperature is lowered until 39° Fahr. is reached, at which point a wonderful change takes place. Now the continued application of cold will cause the water to expand, so that water at this temperature possesses the curious property of expanding by the application of either heat or cold. Water at this temperature is, therefore, in its most condensed condition, and hence 39° has been called the point of the maximum density of water. It may be well imagined that this peculiar property has not been conferred upon water without some very good reason existing therefor, and this reason we can easily understand if we recall to memory the different circumstances under which we should be placed if matters in this respect were not as they now are. If this liquid were to obey the general law and contract by cold at all temperatures, such effects would be produced that our climate would soon be scarcely habitable, and many parts, even of Europe, would be rendered quite unfit for man's existence. Our lakes and rivers would in a short time become solid masses of ice from top to bottom, which would rarely or never be completely melted, so that fish and all other inhabitants of these storehouses of animal life would ere long cease to exist. The water of wells and water-courses liable to freeze would, during the first hard frost, be rendered solid throughout, which would most effectually cut off our supplies of water, so that, if we escaped alive from the rigour of the climate, we should be in imminent danger of perishing of thirst.

These dire catastrophes, however, have all been rendered impossible by this peculiar property which has been conferred upon water.

To understand how the effects just described would be produced if water obeyed the ordinary law, let us bear in mind, first of all, that when a substance contracts it becomes specifically heavier. Thus, a piece of iron at a temperature of 32° weighs much more than a piece of the same metal of exactly the same size at a temperature of 500°; and in the same way would a quantity of water at 32° be heavier than the same bulk of water at 40°, if the ordinary law had held good in its case. Supposing, then, for the sake of illustration, that water exhibited no exception to this law that substances expand by heat and contract by cold, let us look for a moment at what would be the effects of one night of hard frost in our country. The sun sets, the air gets cold, and it immediately begins to cool

the surface water of the lake, on the banks of which we are supposed to be making our observations. This water, by being cooled, would of course become heavier, and would therefore sink, warmer and lighter water rising to occupy its place. In a very short time this water would also be cooled by the cold air, and would sink, giving place to warmer water from below, and so this circulation would continue until the cooling operation had gone so far that the top layer had fallen to 32°, when of course it would become ice, and would forthwith sink to the bottom. Another portion would take its place to undergo the same change, and so the freezing operation would rapidly proceed until the whole of the water of the lake, no matter what its depth, would be converted into a solid block of ice, which, in the case of most lakes, would be of such thickness as easily to withstand the liquefying effects of our summer sun. The same effect, it is hardly necessary to remark, would be produced on all waters—whether rivers, ponds, or wells—which are liable to be affected by frost. What this would lead to can hardly be imagined. The inhabitants of England, under the conditions which would result, might be able to keep themselves alive, but life in such circumstances would not be desirable, certainly not enjoyable.

From this we are in a position to form an idea of some of the results which would have taken place if water had at all temperatures obeyed the general law, and expanded when heated and contracted when cooled; and having seen this, let us now investigate carefully what really does occur when water freezes. For this purpose we will again take our stand on the banks of a lake—preferably on a clear winter evening—and at once commence operations by ascertaining by means of two thermometers the temperature of the water at the surface and at the bottom, and we find, let us say, that these are 48° and 46° respectively. A cold wind sweeps over the surface of the lake so that the temperature of the water there is speedily reduced, let us say, to 44°. By this reduction in temperature it contracts and becomes specifically heavier, when of course it sinks and displaces the comparatively light and warm water below, which rises to the surface, gets cooled below 44°, and immediately falls, displacing the warmer water at the bottom, which in turn rises, gets cooled, and falls, its place being again supplied by lighter and warmer water. And so the cooling and sinking process goes on, the upper thermometer always indicating the highest temperature, when suddenly the magic point 39° is reached, when all movement at once ceases. The upper layer of water is still exposed to the cooling influence of the wind, and it speedily falls in temperature, but it still retains its place. Our upper thermometer shows plainly that the water which surrounds it is being rapidly reduced in temperature, but the lower one remains stationary at 39°. At that temperature we know that water is heavier than at any other, and there like a stone it remains at the bottom, and as it is fully protected from outward influences by the mass of superincumbent water, its temperature remains very much at the same point. The water on the top, however, having nothing to protect it, gets colder and lighter every moment. Down the thermometer goes to 37°, 35°, 32°, and then a slight breeze ripples the surface, and the next moment a thin sheet of ice spreads itself over all. The ice, however, is colder and lighter than the water, so that it floats on the surface and acts as a blanket, protecting the comparatively warm and heavy water below from being cooled. During even the severest winter, therefore, only a thin superficial layer of ice is formed, which serves all the useful and ornamental purposes required of it, and when its duty is finished it readily melts and disappears under the genial influence of the first few warm days of spring.

In another respect than that just mentioned water is peculiar, and is accordingly admirably suited for many purposes to which it is applied. What is known by scientific men as specific heat is in the case of water very high. Indeed, water has a higher specific heat than any other single substance known, and we shall presently see how this property renders water so useful to us.

What is meant by this term specific heat—or, as it is sometimes called, capacity for heat—may perhaps be most easily rendered plain by saying that it refers to the temperature to which a given quantity of a substance will be raised by the application to it of a certain quantity of heat. All substances are not affected in this way to the same extent; hence we say the capacity for heat or the specific heat of different substances is dissimilar. If, for example, we take a pound of water and a pound of mercury and add to each precisely the same amount of heat, we shall find that while both have risen in temperature, the mercury has done so to a much greater extent than the water. Mercury, therefore, it seems, is much more easily heated than water, and this fact is expressed in scientific language by saying that the specific heat of mercury is lower

than that of water, in which respect, as already indicated, mercury is similar to every other single substance with which we are acquainted.

The exceptionally high specific heat possessed by water is useful to us in different ways. For instance, if we in Great Britain, instead of having water encircling our shores, had been surrounded by an ocean composed of mercury or of some other liquid possessing a similarly low specific heat, our climate would have been of a very different nature from what it is. A liquid having a low specific heat is, we know, easily raised or lowered in temperature, so that our mercurial ocean when the summer sun beat upon it would very speedily become warm, and that without absorbing much heat. The air, accordingly, being much influenced in temperature by the heat of the ocean, would soon become uncomfortably hot. And on the other hand, when the sun got less strong and winter winds began to blow, the mercury ocean would very quickly become cold, and the air of course would speedily do likewise. Our climate, therefore, would be very variable, and subject to great and sudden alternations of heat and cold. In summer it would be overpoweringly warm, and in winter unbearably cold. Surrounded, however, by an ocean of water with its high specific heat, such unpleasantly extreme changes are impossible. When the blazing summer sun beats on our shores, an enormous amount of heat is absorbed by the surrounding water without it being thereby rendered much warmer; the air is, therefore, kept comparatively cool. When, on the other hand, chilling influences, in the shape of winter winds, come into play, the ocean, being very difficult to cool, retains its heat for a long time, and as a matter of course keeps the air above it tolerably warm. In consequence, then, of this great capacity for heat possessed by water, we can never, in our insular position, suffer either the scorching heat or the severe cold experienced in continental summers and winters.

In another way this valuable property renders water useful to us, and that is as a cooling agent. We know that nothing will cool us more quickly or completely than water, applied either externally or internally, and this power, it need hardly be remarked, is owing to its high specific heat.

We have already seen that water expands when it is cooled beyond a certain point; on changing from water to ice it expands still further—to the extent of 1-11th part of its volume, so that 11 volumes of water will form 12 volumes of ice. The expansion consequent upon this change from the liquid to the solid state takes place with almost irresistible force. Strong iron bottles are immediately ruptured by it, and we are all aware of its destructive effects as illustrated in the bursting of the water-pipes, &c., of our dwellings, which sometimes occurs during an unusually severe frost. This force is one of the most important agents in the disintegration of our rocks and soils. This important process is effected by water in the summer-time percolating into fissures and cavities of the rocks, which, when the water changes to ice during the cold of winter, are rent and torn asunder by the enormous expansive force thus generated.

Water is one of the most abundant substances in nature, two-thirds of the earth's surface being covered with it. It is also present in the air in enormous quantities in the form of vapour; as snow it covers the summits of many mountains, and as ice it forms the vast "floes" or "fields" in the Polar regions. It is also present in most animal and vegetable substances, and even in many minerals.

Taking vegetables, for instance, there is in turnips and cabbages 90 per cent. of water; in mushrooms, 96; in cucumbers, 97; in apples, 80; in potatoes, 75, and so forth.

All natural waters are more or less impure, and as water is in such common use for dietetic purposes it becomes a matter of great importance to be able to distinguish sharply and decidedly between water which is dangerously impure and that which, though very impure from a chemical point of view, is yet perfectly wholesome. The solving of that problem belongs to the domain of analytical chemistry, and does not in any way come within the scope of this paper. It will not, however, be altogether out of place to mention briefly one or two of the more common impurities of water, such as are found in our lakes, rivers, and wells. Absolutely pure water is not suitable for drinking purposes; for, besides being insipid and uninviting, and even to some people nauseous, it is positively unwholesome. Bright, fresh spring water, such as is at once both pleasant and wholesome, is, strictly speaking, very far from being pure. It contains in solution not only different gases to which it owes its bright, sparkling appearance and invigorating and refreshing taste, but also a certain amount of earthy matter, such as carbonate or sulphate of lime, or similar salts of magnesia.

When these earthy matters are present in small proportions only, they do not affect injuriously the character of the water containing them, but if they occur in excessive quantities, as they frequently do,

they then most seriously impair its usefulness for many domestic purposes. Waters which contain only small quantities of these lime and magnesia compounds are said to be "soft," while those which contain them in greater proportion are described as being "hard."

It is not advisable to use habitually a very hard water either for culinary or dietetic purposes; the presence, however, of a fair amount of these saline impurities—the occurrence of which constitutes "hardness"—rather increases than impairs the value of water as a beverage. There are, though, it should never be forgotten, certain other impurities sometimes found in water which render it quite unfit for use, and which have, indeed, been the cause of much disease and suffering, when water containing them has been used for dietetic purposes.

Of the manifold uses of water it is almost unnecessary to speak; they are universally known and appreciated. In each of its three conditions this most invaluable substance is of incalculable benefit to mankind, from a sanitary and economic point of view, as well as a medical agent, and an aid in various scientific researches.

The extent to which ice is now employed by people in general as an article of utility and luxury may be imagined when we learn that in the London district alone, 100,000 tons are used in this way during the season; while in New York, where it seems to be in much greater request, 600,000 tons are used in the same time; while, with a laudable attempt, no doubt, to moderate the heat often felt and displayed by some of our more zealous legislators, no less than one ton per night of ice is used in the refrigerating department of the House of Commons.

In water we have not only an immense storehouse filled with countless numbers of creatures fitted for food, but we also possess by its agency a most efficient highway between countries widely separated, and which could not be brought into communication with the same ease by any other means.

The water of the sea also acts as a vast cesspool, which receives all refuse matter from the land, and not only receives it, but so alters and chemically changes it as to render what would assuredly become on land highly noxious and prejudicial to health quite inert and harmless.

Water, also, in consequence of its great solvent powers, is a most valuable detergent agent. Indeed, no other substance that we are acquainted with could replace it in cleansing operations. It is also invaluable—in fact, indispensable—as a beverage and as a cooking agent.

Besides being so exceedingly useful, water is also in the highest degree ornamental, contributing not a little to the beautiful and charming variety of the globe which we inhabit. The ever-changing masses of cloud, and the gorgeously coloured rainbow, which it is impossible to contemplate without feelings of admiration, are due to the action of watery vapour on sunlight; and we are all aware how much the landscape owes to the effect produced by water, whether in the form of the clear placid lake, the slowly flowing river, or the bounding waterfall, or by the various phases assumed by that "image of eternity," the dark and deep blue ocean.

In its third condition of vapour, we have also an agent of great utility, and it is only necessary to mention the word "steam" to recall what we in this country owe to water-gas. By the aid of this giant we may be said to maintain our supremacy among the nations. By it we move our huge ironclads, weighing many thousand tons, from place to place as if they were toys, and by its means we can transport ourselves on the iron roads which it has made for us at a speed exceeding that of the fleetest racehorse. Our 80-ton guns and our pens are produced by the agency of the same power, which drives also our cotton-mills and our printing-presses, our lithographing machines and our paper-making machines, and which also not only ploughs the land and reaps the crop, but besides grinds the flour and makes it into bread.

Many things which we regard as of the highest utility can to a certain extent be replaced by others, but nothing can replace water. The world at one time got on without iron, without even coal, but never without water. It being so necessary to our existence and happiness, bountiful Nature has made it very plentiful, and on that account it does not, as a general rule, excite either surprise or admiration in the mind of the ordinary beholder; notwithstanding this, however, water is not only a substance of the greatest importance, but it becomes to us, when we have made ourselves conversant with its many wonderful properties and the beautiful and complete mode in which it fulfils its numerous and all-important functions, a subject of profound interest and admiration.

NUGGETS AND QUARTZ.

By G. A. Lebour, F.G.S., Lond. and Belg., F.R.G.S., etc.

Lecturer in Geological Surveying in the University of Durham College of Physical Science.

THE announcement "pure gold" is so frequent in our shop windows and elsewhere that it may seem strange to say that until the last year or two no such thing was known. Yet this is strictly true. With infinite pains and numberless precautions the chemist of the Mint has succeeded in preparing a standard gold plate in which the most delicate tests fail to recognise the presence of any impurities; and this is the first time that really pure gold has been seen. One of the most experienced of assayers was therefore perfectly justified in declaring recently that he had never met with pure gold in nature; and, further, that he had never met with native gold free from silver.

But if it be true that the finest gold-dust and the largest nugget both contain silver in every case, and commonly several other foreign substances, it is also true that the proportion of these things is so small that one of the characteristics of gold is the "clean" state, so to speak, in which it is chiefly found. Indeed, hitherto, almost all the gold dug has been "native." In time to come this will probably not be so much the case.

Inexperienced people have often mistaken a variety of minerals for gold—bright yellow mica or pyrites * generally—but a very limited knowledge of its properties would have saved them from the possibility of error. The great weight of gold alone separates it sufficiently from all substances at all resembling it in colour. Then it can be beaten out into thin sheets in a manner unapproached by other metals, whilst the way in which it stands the ordeal of fire, only melting when the heat reaches about 2,840° Fahr., and coming out of the furnace practically unscathed, is also unique.

All these qualities, added to the difficulty of finding it, have long ago placed gold at the head of the aristocracy of metals. Since the days when Pactolus rolled over its golden sands, men have sought for it, fought for it, and died for it. No fruit of the earth has been so long studied and speculated on. Nevertheless, none has been so little known, or so thoroughly misunderstood as to its circumstances of deposition and mode of origin.

So far as we know at present, gold, in its most ancient setting, occurs associated with quartz, or impure rock crystal, in veins cutting through rocks of various ages, but mostly belonging to the older divisions of the "Palaeozoic" series (FRONTISPIECE, Vol. I.), and also disseminated in those rocks themselves.

These gold veins differ in some essential particulars from ordinary veins, such as those containing copper, lead, or tin. They form courses of quartz varying from a few inches to a hundred feet or more in width, running through the beds of rock like great dykes, and often, owing to the great hardness of the quartz, standing out like walls

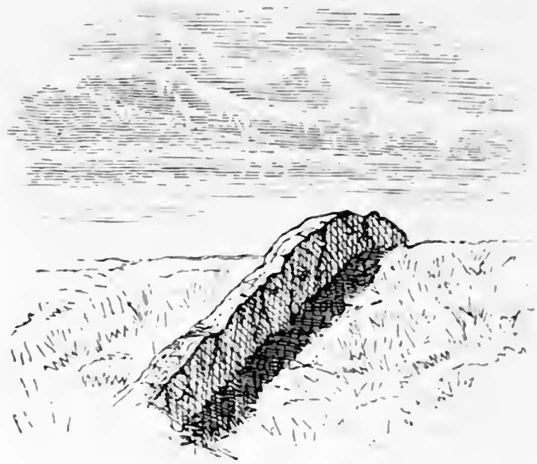

Fig. 1.—A Gold Quartz "Reef."

many feet above the surface of the country. Hence the appropriate name "reef" applied to them (Fig. 1).

At other times reefs are irregular, shapeless, quartz-filled spaces, without apparent order, and very unlike lodes of baser metals. In Fig. 2 we have a section showing a Victorian gold vein of this character. It will be seen that no dislocation of the encasing bedded rocks necessarily attends the presence of reefs. It will also be noticed that from surface appearances little or nothing could, in cases of this kind, be predicted as to the probable width, direction, or continuousness of the vein below ground. Still, by dint of practice, gold prospectors have come to know—or to think they know—when the quartz looks "kindly"—that is, whether it is likely to hold gold or not. If the "kindly" look

* Chemically, sulphide of iron—the same substance which is known as "diamonds" in roofing slates, and as "thunder bolts" in the chalk.

be justified, gold *may* possibly be seen at the outcrop of the reef, but more usually it will have to

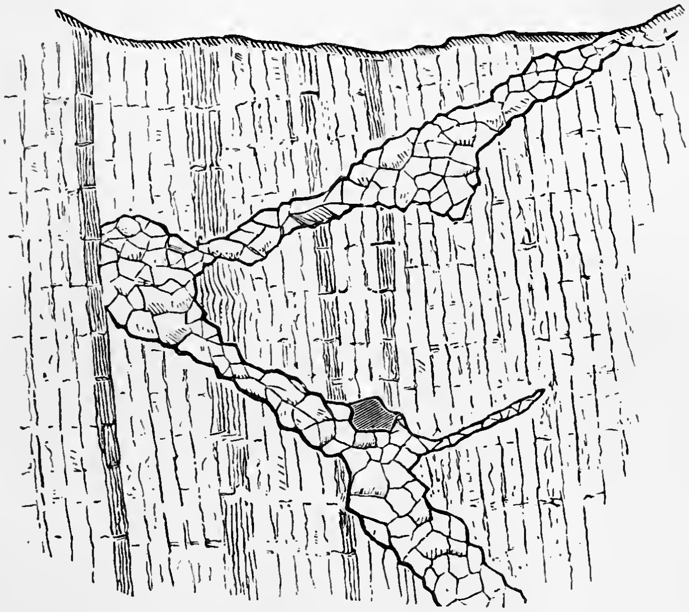

Fig. 2—Quartz "Reef" at Fryer's Creek, Victoria.

be separated, by hard and tedious mechanical labour, from the quartz in which it lies concealed in specks too small for the eye to distinguish. In either case the surface appearances are apt to be deceptive, for auriferous quartz contains many other substances besides gold—and those, too, in a chemical form that renders them peculiarly liable to decomposition by atmospheric agencies. Now, the quartz being to some extent held together, as it were, by these substances, becomes, when they are decomposed, itself crumbled down, and the heavier unaltered and almost unalterable gold remains at the surface, *minus* much of the matter which originally accompanied it. It follows, therefore, that a reef is often richest at the surface—not, as has for years been very generally believed, because the gold occurs in greater quantity in the upper portions of the reefs, but by a mere effect of wearing away. At the present day, in California and elsewhere, gold-mines are being worked which have grown richer and richer as they got deeper.

Although, as has been mentioned above, the gold is not often visible to the naked eye in the quartz, it occasionally happens that lumps of considerable size are found embedded in the white or reddish quartz rocks—the "matrix" of geologists. Thus, a hundred-weight of gold was once found in a reef in New South Wales, in blocks, of which the largest was a foot across, and weighed seventy-five pounds.

We have no means of ascertaining the exact geological date of the in-filling of the reefs, but there is much good reason for believing that it took place chiefly at the close of the "Palæozoic" times. From that period to the latest within the scope of geology the history of these veins is a blank. We know nothing of them until we see them in "post-tertiary," or, as some say, "quaternary," times, cropping across the exposed edges of the uptilted and altered rocks, much in the same position as we find them now. Then, as now, the decomposition along their exposed edges was carried on chemically by air and rain, the eroded quartz—"mice-eaten," as the miners call it—detached itself and crumbled, leaving the heavier gold behind it, and then, as now, or perhaps more than now, the constant waste of the land called "denudation," slowly but surely carried on its work of destruction and change, transporting quartz and gold, as gravel and nugget, to the neighbouring slopes and gullies, and as sand

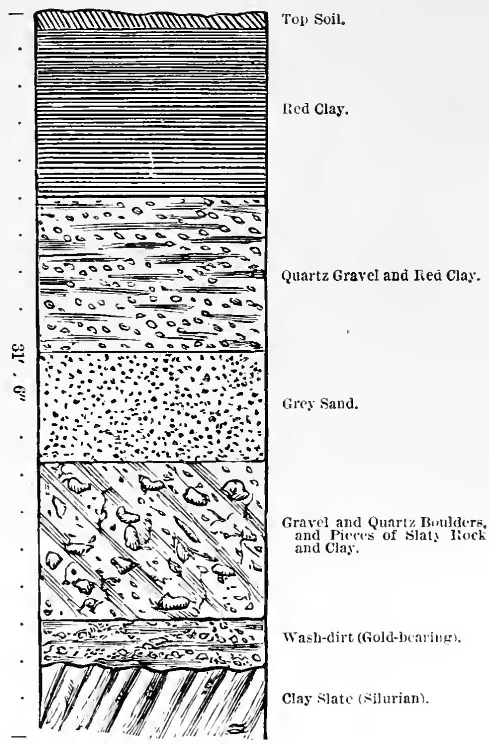

Fig. 3.—Section of Gold-bearing Drifts at Dunolly, Victoria.

and clay and dust to the more distant river-valleys. The quartz-miner imitates Nature in a rude way by crushing the quartz in stamp-mills, and then collecting the gold from the crushed mass by various chemical expedients.

It is in these gravels, sands, and clays—collectively known as Drift—that nine-tenths of the gold of the world have been found. It is only within recent years that the parent reefs have been systematically attacked. In these Drifts (Fig. 3) the gold-digger of early Australian and Californian times worked. They are still the poor man's diggings, requiring little capital to wash out the gold, while the quartz-reefs demand a considerable outlay. In California they are known as "placers." The depth of the Drift is always very limited, but that of the reefs has practically no limit.

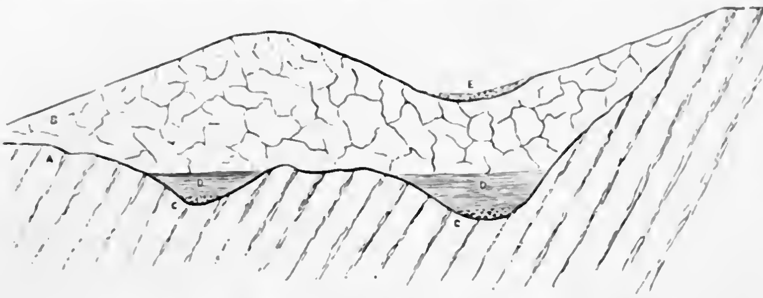

Fig. 4.—Diagrammatic Illustration of a Digger's "Claim."
(A) Bottom Rock (Silurian); (B) Basalt (false bottom); (C) Rich Wash-dirt; (D) Older Drift; (E) Newer Drift, with existing Stream.

The Gold Drifts are relatively of different ages. Thus, they consist not only of deposits due to existing streams, but often represent the *débris* brought down by rivers long since dried up and lost. In Australia this has more than once been illustrated in this manner. A lonely digger, whom, in his own slang, we will call a "hatter," opens out a solitary "claim" (Fig. 4) in the valley of an existing water-course, and sets to work digging and washing. The gold-bearing loam, or "wash-dirt"—the "pay-dirt" of the Californian—is poor, and after a time the "bottom" or hard rock is reached. The miner's hope rests on getting to the "bottom" or "bed rock." Here the heavy gold worked down by the stream will have settled. If it is to be found anywhere, it will be here. If the "bed rock" has stopped no riches in their course, then all further search is useless, and the disappointed "hatter" strikes his camp, and departs to other fields. Soon after comes the digger's gleaner—the humble "fossicker." He is content with smaller earnings than his predecessor, and works the deserted "claim" in his turn. By luck, or instinct, or perhaps even by experience, he fancies the hard rock may be but a "false bottom," and by dint of patient toil sinks through it. Fortune (in this imaginary case), favours the brave, and, sure enough, below the bottom rock, clays, sands, and gravels occurs once more, —with possibly a rich auriferous wash-dirt and "cement," or conglomerate, at the base, resting, this time, on the denuded Palæozoic beds—the true "bottom." Here let us leave our "fossicker" rejoicing in a "lob" of gold such as in real life "fossickers" seldom find, in "spangle," "paint," "flour," "heavy," "shotty" gold, and "nuggets"—and see how geology explains the matter.

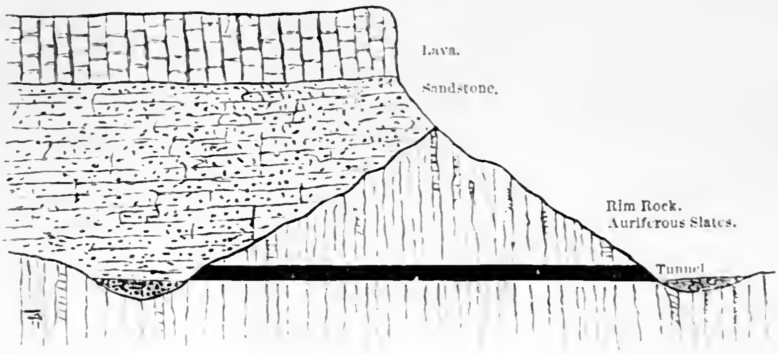

Fig. 5.—Maine Boy's Tunnel, illustrating the old Lava-covered Gold-Drifts of California.

In the valley, *c*, there accumulated in long-past times the auriferous Drift from the hills. Then came the overflow of a volcanic eruption, filling the valley with lava—now basalt. Such eruptions were frequent in Australia up to almost within the historic period. Next followed the inevitable "denudation" or wearing away of the cooled and hardened lava, the bottom rock of the unsuccessful "hatter," and the establishment of the existing stream with its valley and gold-bearing deposits—necessarily poorer, however (time of formation and reduced area considered) than the older and lower "wash-dirt." Though our "hatter" and

"fossicker" be persons of no particular consequence, they have served to illustrate facts of common occurrence in Australia and North-west America (Fig. 5). The great gold "leads" of Ballarat are, many of them, merely old river-beds underlying, and, so to speak, "bottled up" by, great sheets of basaltic lava; and the same thing happens in the Far West.

In some rare instances true gold lodes are found unassociated with quartz. They thus occur in Transylvania, at the Vöröspatak mines, where veins of carbonate of lime are worked of which the sides or "cheeks" consist of symmetrical layers of gold varying from one-half to one millimetre in thickness. In this exceptional case, the containing or "country" rock is of igneous origin —an old quartzose lava known as Dacite—and the gold is often beautifully crystallised in perfect cubes and octahedra.

But besides occurring in detached and more or less rolled fragments in Drift, or encased in the quartz of reefs, or less frequently in other forms of veins, gold is found disseminated widely, though thinly, throughout the rock-formations of the world. In this condition, however, so minute usually are the proportions in which it has hitherto been detected, that its presence can only be made manifest by means of delicate chemical tests. The ancient quartzites of Scotland, the basaltic dykes of Britain, the Carboniferous Limestone of Bristol, the Coal-measures of New South Wales, the Triassic and Jurassic rocks of the Continent—all these have yielded the precious metal to the analyst.

Such are the leading facts. How are they explained? Whence this all but universal presence of gold? whence its concentration in certain veins? and whence its wide dissemination in rocks of all ages? Conclusive answers to these questions there are none, probable answers there are a few, but of possible and impossible the number is, as might be expected, great.

Were the fissures or veins filled by the condensation of heated fumes from below, from the interior of the earth? or by depositions from mineral waters similarly heated? Or were they filled entirely from above, from the tricklings and evaporations of our surface waters? Are the veins the result of all these agencies combined? These are a few of the oft-discussed but still doubtful points as to lodes. But they scarcely touch the subject of dissemination in sedimentary rocks. Here there are but two probabilities. Either the gold is due to the erosion of pre-existing veins—and this is undoubtedly true for *some* of it—or it is due to the *sea*.

This last alternative is perhaps startling, but when we add that it is now ascertained that all sea-water contains *some* gold, and when we reflect on the timeless age of the ocean, on its presence in former times wherever bedded rock is found, it will be readily admitted that here, at last, we may have a cue to the origin of much of the gold as we now find it. But Nature loves to work in various ways, and if we must, according to the present state of our knowledge, look to the sea as the great golden treasury of the globe, we must yet remember that co-operation from some of the other sources enumerated above may also have been brought into play.

THE SUN OUR FIRE, LIGHT, AND LIFE.

By Richard A. Proctor.

I CONSIDERED the sun as ruler of the solar system before considering him as the source of nearly all the light and heat received by that system, because the study of the heavenly bodies and their movements leads us first to recognise the sun's power as a ruler. It is in this power in fact that we find the explanation of motions which otherwise could not possibly be understood. It is only because the sun's mass, and his consequent might, have been fully recognised, that the system of modern astronomy is regarded as established. So far as the mere movements of the planets are concerned, the theory of Tycho Brahé would have as good a right to our acceptance in these times as that of Copernicus. But when once we perceive that these movements are ruled, and that mass or quantity of matter measures the ruling power, we see in the sun the chief ruling body. It was natural, then, that we should first study his action in this capacity. Otherwise it would have been natural to consider the sun first as the light and fire of the solar system; for certainly men noticed his light and heat long before they recognised his ruling power.

The brightness of the sun's surface is obvious to

the eye. No telescope is needed to tell us that that surface is so intensely lustrous that no large portion of it can be looked at directly without pain. But some will be surprised to learn that it makes little difference—so far as the intrinsic brightness of the sun's light is concerned—whether we look at him directly or through a telescope, and that it would make no difference in that respect if we could approach him much more nearly, or recede from him to the distance of Saturn, Uranus, or Neptune. We should, of course, get much more light from him than we do if we were as near to him as Mercury, and much less than we do if we were as far away as Neptune; but that would be because his apparent size would be increased in one case, and diminished in the other. His enlarged or diminished disc would be of the same brightness as at present. In a large telescope also the sun's total light is greatly increased; but his apparent size is even more increased (for the thick glasses of large telescopes absorb a portion of any light which has to pass through them), so that his surface-brightness is rather less when he is seen in a telescope than when he is looked at directly.

We may say, then, truly, that the sun is as bright as he looks, or, rather, that but for such absorption as our air exerts on the sun's rays, he would look as bright as he really is. This absorption is such that when he is nearly overhead, on a very clear day (at the sea-level), about two-thirds of his light reaches us.

Comparing his lustre with earthly lights, we may say that it exceeds in intensity the brightness of the lime-light in the oxyhydrogen flame, at its greatest obtainable intensity, about 140 times. Sir John Herschel says 146 times. The electric light *can* be raised almost to the brightness of the sun's surface; but under ordinary conditions its brightness is not quite half that of the sun.

But while the brightness of the sun is thus amazing, the total quantity of light he emits is infinitely more so. Every square inch of a surface exceeding that of our earth 11,750 times is glowing with a lustre exceeding 140 times that of a square inch surface of lime under the oxyhydrogen flame. The merest point of light in the case of the electric flame illuminates with what seems like the light of day a surface of many hundred square yards; and in the case of the sun it is not a mere point, but a surface of some $2\frac{1}{4}$ millions of millions of square miles, which is glowing with a brilliancy exceeding more than twofold that of the electric light.

Add to this the consideration that a large portion of the light emitted by the sun is absorbed by his own atmosphere. For the disc of the sun is not uniformly light, but shaded off towards the edges. The actual surface is thus even more intensely bright than the central part of the sun's face as we see it. But even this is not all. We have seen that the sun's surface appears mottled and granulated, the granules being far lighter than the background on which we see them. Probably nine-tenths of the sun's light come from the granules, which, if we could see them as they really are, would probably be found to occupy not much more than a tenth of his entire surface. For they are all expanded in appearance by the optical effects known as *irradiation* and *diffraction*. Thus, it would probably not be an exaggeration to say that they are nearly a hundred times brighter than the background on which we see them. If so, their brightness is ten times greater than the average solar surface brilliancy, which is itself probably twice as great as the lustre of the surface as seen from without, while we on earth, even under the most favourable circumstances, lose a third or thereabouts of the surface brilliancy of the sun, as he would be seen from the moon or any airless planet.

The emission of solar heat is even more marvellous, for it indicates the constant activity of forces of inconceivable energy.

The sun is as hot as he seems to be, in the same sense that he is as bright as he seems to be—allowance being always made for absorption in his own atmosphere and in our own. By noting the actual amount of heat received on the earth from the disc of the sun, we can tell the total amount emitted (not the total existing amount) from the globe of the sun. Sir J. Herschel and Pouillet have done this independently, by finding out the rate at which the sun's heat melts ice. Their results agree well together. These results show that the heat falling on a square mile of the earth's surface from a sun overhead would melt 26,000 tons of ice in an hour. The earth receives about 50,000,000 times as much. But the earth only captures about one two-thousand-millionth part of all the heat which the sun emits. Thus the total heat emitted by the sun would suffice to melt 2,600 trillions* of tons of ice per hour. This emission corresponds with what would result from burning 11,750 billions of tons of coal per *second*. The rate of solar radiation of heat is easily remembered if we note that,

* I follow the English, not the French system of notation. Thus, by billions I mean millions of millions; by trillions, I mean millions of millions of millions; and so forth.

supposing our earth's surface as hot as the sun's, she would emit as much heat per second as would result from the burning of one billion tons of coal.

It is a singular circumstance, by the way, that of all the tremendous work implied by the emission of solar heat, only a very small portion seems utilised. I have mentioned that the earth captures about 1 in 2,000 millions of the solar rays. All the planets together capture about 1 in 227 millions. The rest —that is, 227 millions of rays for every one which falls on a planet—pass into the star-strewn depths. They may reach planets travelling round other stars, just as the rays of Sirius and Vega, Arcturus, Capella, and Aldebaran, reach our earth. But it is as difficult to perceive how their energies can be thus utilised, as to understand how such trifling supplies of heat as we receive from the stars can produce any effects corresponding to the enormous amount of seemingly wasted energy which they represent.

We must now study the physical condition of the orb which is thus the fire and light, and therefore in effect the life, of the solar system. We have here a subject which has grown marvellously in interest during the last few years. In fact, it may almost be said that the study of the sun's physical condition by other methods than mere telescopic observation, was not even commenced before the present century.

We have first to consider the results of the investigation of the sun's light with the spectroscope. The optical relations involved in this investigation, and to some degree the physical relations also, belong to other departments of science than astronomy, and will be fully dealt with elsewhere. Here it is only necessary to state the laws which are to guide us in the interpretation of the various results of spectroscopic inquiry into the condition of the heavenly bodies.

We find that when the light from a solid or liquid body white with intensity of heat is caused to pass through one or more triangular prisms of glass, the white light is spread into a rainbow-tinted streak or spectrum, the different colours whose mixture forms the white light being bent in different degree by the action of the prism or prisms, so that they travel in different directions as they leave the last prism. The red rays are least bent, the orange next, the yellow next; then, in order, the green, blue, indigo, and finally the violet. And when care is taken—by allowing the light to shine only through a fine slit—to cause the several tints of each colour of the rainbow to travel clear of neighbouring tints, it is still found that a perfect rainbow-tinted streak is produced, the red merging into the orange, by insensible gradations, the orange into the yellow, and so forth. In other words, no tints are wanting in the light of glowing solid or liquid matter, wherefore its spectrum is a perfect, or, as it is technically called, a continuous rainbow-tinted streak.

But the light of the sun, when analysed in the same way, is found not to contain all the tints of the rainbow. Newton, indeed, in his original experiments on the sun's light, obtained the result which I have just described as happening in the case of glowing solid or liquid matter, but that was because he did not sift the light finely enough. Wollaston first, and later (and much more completely), Fraunhofer, making fine the slit through which they examined sunlight, found first that a few and afterwards that many tints are missing from sunlight. Fig. 1 is a picture of the solar spectrum (uncoloured, but the colours are indicated verbally below it), with the chief dark lines (or missing tints) noted by Fraunhofer. But to understand the nature of his work the intermediate finer dark lines must be described:—A is a well-marked line near the red end of the spectrum; B is a strong and broad line in the red. Between A and B is a band of several lines called *a*; C is a dark and very strong line. Between B and C Fraunhofer counted 9 fine lines; between C and D about 30—D is a double line. Between D and E Fraunhofer counted 84 lines—E is a band of several lines, the middle line stronger than the rest. At *b* are three strong lines, the two farthest from E being close together. Between E and *b* Fraunhofer counted 24 lines; and between *b* and F more than 50. F, G, and H, are strong lines. Between F and G and between G and H, Fraunhofer counted 185 and 190 lines, respectively, and even between H and I, where

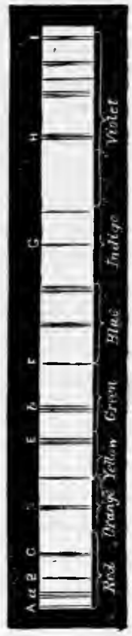

Fig. 1.—The Solar Spectrum, showing the Fraunhofer Lines.

> "The last gleanings of refracted light
> Die in the fainting violet away,"

he still found many dark lines, or, more correctly, he found that many tints are missing.

I have been thus particular in describing Fraunhofer's results, because his lines are constantly

referred to in describing spectroscopic researches, and his inquiries supplied in reality the basis of the modern science of spectroscopic analysis. It must be understood, however, that modern observations reveal a far greater number of lines than Fraunhofer saw. In fact, it may truly be said that while in sunlight there are all the colours of the rainbow, yet thousands of tints are missing from the red, thousands from the orange, and, in fine, tens of thousands from the spectrum as a whole.

Now, the interpretation which science has found for these missing tints is that they show the action of the vapours of certain elements in absorbing light emitted by the sun. It is found that every substance, when in the vaporous form, and glowing with intensity of heat, shines with certain tints only. Its light, dealt with by the spectroscope, does not form a rainbow-tinted streak, but simply produces a certain number of coloured images of the slit through which the light is received. One substance, sodium, shows only a strong double orange-yellow line, and a few faint lines belonging to other parts of the spectrum. Hydrogen shows four bright lines, one red, one green, one blue, one indigo. Iron shows about 450 lines of all the colours of the rainbow, but still they represent only 450 tints among the infinity of tints forming the rainbow-tinted spectrum. But it was also found that a vapour has the power of absorbing the same tints which it emits. If a mass of glowing solid or liquid matter is shining through a mass of glowing vapour, and the spectrum of both is examined, we find that the rainbow-tinted streak from the solid or liquid is crossed by dark or bright bands corresponding to the tints of the vapour. The lines are dark if the vapour is cooler than the solid (and so absorbs more of its own special rays than it emits), and bright if the vapour is hotter than the solid (and so emits more rays than it absorbs). If both substances are at the same heat, we have a rainbow-tinted spectrum without either dark lines or bright lines; in other words, we find in this case no evidence in the spectrum to show that the light from the glowing solid or liquid body has passed through the glowing vapour. In point of fact, we may say that in such an experiment the tints belonging to the vapour's spectrum are just as strong as though the glowing solid or liquid were not present at all; so that they appear (1) as dark lines, (2) as bright lines, or (3) are lost, in the rainbow-tinted background, according as (1) they are fainter or (2) stronger than that background, or (3) of the same lustre.

We see, then, that the dark lines in the sun's spectrum indicate the presence of vapours around the sun, which are cooler than the sun's mass. If any bright lines should be made out they would indicate the presence of vapours hotter than the general mass. And lastly, many vapours may exist of whose presence we can obtain no spectroscopic evidence, simply because they are at the same temperature as the general mass of the sun.

Studying the dark lines in this way, it has been found that hydrogen, sodium, barium, magnesium, calcium, aluminium, iron, manganese, chromium, cobalt, nickel, zinc, copper, titanium, and other elements, exist in the sun's atmosphere, and are nearly always cooler than the sun's surface. Occasionally the lines of hydrogen are seen bright when certain parts of the sun are examined, showing that at such times the hydrogen there is hotter than the surface underneath it. Again, it has lately been found that the bright lines of oxygen, and probably those of nitrogen, are present in the solar spectrum. This discovery, which is due to Dr. Henry Draper, of New York, shows that oxygen, and probably nitrogen, are present in the sun's atmosphere, but are hotter than the glowing surface above which they are situate.

The same method which has thus shown the sun to contain many elements familiar to us on earth, and probably to contain many others of our elements, has taught us something also of the matter underlying the general surface of the sun. For when the light from sun-spots has been examined, it has been found that the dark lines belonging to some elements are broader and darker than in the spectrum obtained from the sun's surface as a whole. This shows that at the spots, which, as we have seen are regions depressed below the general surface, the vapours of those elements are denser and, at the same time, probably cooler than elsewhere. In other words, the darkness of spots is due to the existence of large quantities of relatively cool vapours in these great cavities or depressions.

So also the faculæ are found to give a spectrum somewhat different from the general solar spectrum. Not unfrequently the lines of hydrogen are bright in the spectrum of a facula, showing the presence of hydrogen more intensely heated there than over other parts of the sun's surface.

Speaking generally, however, spectroscopic analysis gives very little information about parts of the sun below the visible surface or photosphere. The case is very different with parts of the sun outside that visible surface. We have already seen what spectroscopic analysis tells us about the solar

atmosphere, which is of course outside the surface we see. We have now to consider parts of the sun lying outside that complex atmosphere, formed of the vapours of elements which, like iron, copper, zinc, &c., we only see on the earth in the solid form unless we subject them to the intense heat obtained in large furnaces.

It so happens that the disc of the moon is of about the same apparent size as that of the sun. Both discs vary according to the varying distances of the two bodies. The average lunar disc is rather less than the average disc of the sun. But when the moon is at her nearest she looks larger than the sun even at his nearest, and considerably larger than the sun when he is farthest from the earth. We shall have elsewhere to consider how eclipses of the sun are brought about. Let it suffice here to note that whereas usually, when new, the moon passes above or below the sun, she sometimes passes athwart his disc. If, when this happens, the moon is near enough to us, her disc will entirely hide the sun's face for a short time (not exceeding seven minutes under any circumstances). Thus, for a while we see the regions outside the sun's globe without being dazzled by his own splendour. Moreover, our own air towards the sun's place in the sky is for a while in darkness. We can then tell whether close by the sun any matter exists which is usually veiled from view both by his own light and that of the sunlit air.

The first and most striking circumstance noted on such occasions is the existence of a glory of light all round the sun, or rather round the black disc of the moon. But ordinary vision discovered nothing worth noting about this glory until long after the telescope had been applied to examine details round the eclipsed sun. So we may consider here what the telescope has shown, without passing from the actual order of discovery, and with the advantage of considering the parts of the sun outside his globe in the order of distance from his surface.

First, then, the telescope showed quite close to the black body of the moon a number of red objects, such as are shown at A, B, C, D, in Fig. 2. They are compared by some who saw them in 1842 to garnets round a brooch of jet. They were then called the red prominences, and have since retained the name, though they are known now not to be real prominences. Where, as at *a* and *b* in Fig. 2, a long low-lying ridge of this ruddy matter was seen, it was called the *sierra*, a name still frequently used. But unfortunately some one invented for the ruddy low-lying envelope the name *chromosphere*, intended to mean colour-sphere (which would be *chromatosphere*), and it seems likely that this name will remain as a monument of the classical knowledge of English astronomers. It is in reality, as *The Times* has pointed out, as incorrect as *phograph* would be for *photograph;* yet it is now so commonly used, especially among foreign and American astronomers (humouring, as it were, the joke against their British brethren), that it should be known to the learner. However, *sierra* is at once a more correct and a more effective name.

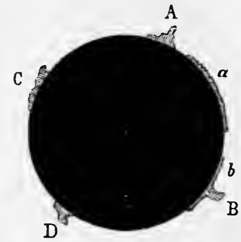

Fig. 2.—Showing the red Flames A, B, C, D, seen round the Sun when he is totally eclipsed, and the shallow red Layer *a*, *b*, called the *Sierra.*

At first these red objects were thought by some to belong to the moon. But De la Rue and Secchi, by taking photographic views of the total eclipse of June, 1860, at different stations, each taking several views, showed that the prominences belong to the sun, for it was found that the moon moved athwart them, and along perceptibly different paths, as photographed from the two stations. Thus it was shown that there are masses of ruddy matter at different parts of the sun's surface, extending sometimes to heights of 70, 80, and even 100 thousand miles. During the same total eclipse it was discovered that the sierra entirely surrounds the sun's disc, or in other words, that the sierra matter entirely enwraps the sun's globe. It had on that occasion a depth of about 7,000 miles.

Next came the analysis of the coloured prominences by means of the spectroscope. This was effected during the total eclipse of August, 1868. On that occasion Tennant, Rayet, Janssen, J. Herschel the younger, and others, found that the light of the prominences shows three principal tints, one orange-yellow, thought at the time to be the sodium line, and the others red and blue, belonging unmistakably to hydrogen. Rayet saw six other lines. It was thus proved that the prominences consist of glowing gas, hydrogen being certainly one of the constituents. We might long have remained in doubt whether the other chief constituent was sodium or not, but for an invention devised, or rather first successfully applied, at this time.

We cannot see the prominences, because of the strong light of the sun. Even if the sun himself is concealed from view, the light of the sky—that is, of our own air strongly illuminated by the sun—

entirely conceals the prominences. If we use darkening glasses strong enough to protect the eye from the solar glare, we obliterate the prominences from view. The light of the sky would be quite strong enough to hide them under any circumstances of ordinary vision.

But when we learn that the light of the prominences consists of certain special tints, whereas we know that the light of the sun contains all the colours of the rainbow, we perceive that if we can obliterate all the light of the sun or of the sky, except those special tints, we shall have enormously reduced that light, while the light of the prominences will be left just as strong as before. So, if we could get coloured glasses which would allow just the colours we wanted to pass through, and absorb all others, we might expect to see the prominences, though of course it might turn out that the sky-light even of these special tints alone would suffice to veil the prominences from view. Unfortunately, we cannot, by means of coloured glasses, allow separate rays to pass through in this way. (I say unfortunately, though the problem has been successfully dealt with in another way, for that would be far the best way for ordinary observation, if only it could be managed, as one of these days it may be.) The spectroscope, however, by actually carrying the rays of different tints in different directions, enables us to deal with them effectively. We can stop off those we do not want, and allow those only to pass which we do want.

This idea occurred to several before the eclipse of August, 1868, though, I believe, the only person who definitely indicated the principle, and showed how it might be applied to the prominences, was Dr. Huggins, whose views were published in the "Monthly Notices of the Astronomical Society" for February, 1868. As far back as 1865 he had shown how the principle bore on the study of other objects in the heavens—the so-called nebulæ of the gaseous sort. Be this as it may, immediately after the eclipse of 1868, Janssen, one of the discoverers of the gaseity of the prominences, applied this method, and was able by means of it to see the bright lines forming the spectrum of the prominences when the sun was shining in full splendour. Of course he could only see one of these lines at a time, but by bringing the different parts of the spectrum successively into view he saw all these lines. He communicated the news of his discovery by letter to Europe, but a day or two before his letter arrived Mr. Joseph Lockyer had seen these lines by the same method.

It was now possible to determine the exact position of the prominence bright lines, for they could be seen in the same field of view as the solar dark lines. It was thus found that the lines ascribed to hydrogen agree perfectly with the dark lines of hydrogen in the solar spectrum. But the orange-yellow line was found not to agree with any solar dark line, though near to the sodium double line. Thus, it was made certain that the prominences consist in part of glowing hydrogen, but the other chief constituent was not identified. It is believed by many that it is an element not known on the earth, and the name *helium,* to signify a specially solar element, has been given to it.

The new method enabled astronomers to tell where prominences existed at any moment round the sun's disc. For, wherever the brighter prominence lines were seen, there, of course, was a prominence as high or as broad, according to the position of the slit, as the lines thus seen. But to search for prominences in this way was slow work. Astronomers heard gladly, therefore, of the invention by Huggins of a method by which the whole of a prominence, even of considerable size, could be seen at once. He simply opened the slit of the spectroscope. This made the spectrum of the sky correspondingly brighter, and of course all the dark lines in it disappeared at once, the multitudinous images of the broad slit overlapping each other, and the spectrum becoming altogether impure. But when the spectroscopic dispersion was great, the special tints of the prominences still remained visible on the brighter background of the spectrum of the sky. And since in the widened slit the shapes of the prominences were included, these special tints showed — each separately, of course — the coloured images of the prominences.

This method at once led to the most interesting results. Prominences could be watched steadily for hours, or even—if large enough to remain so long visible at the sun's edge—for days. Their changes, whether slow or rapid, could be followed, and, where occasion suggested, the other method, which shows the bright lines only, could be applied to particular parts of a prominence to ascertain in what degree, if in any, its chemical structure differed from that of other parts, or of other prominences.

It was now found that the sun's coloured prominences undergo sometimes very rapid and wonderful changes of shape. Here, for instance (Figs. 3 and 4), are two views of the same prominence as seen by Zöllner, the second view being drawn an hour

later than the first. Remembering that the prominence was some 45,000 miles in height at first, it will be seen how rapid must have been the change

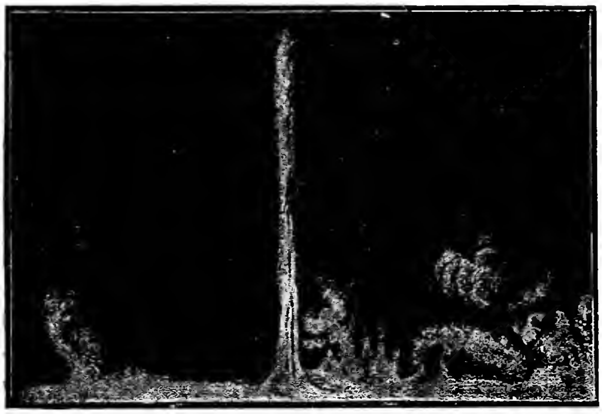

Fig 3.—A Promiuence seen by Zöllner on August 29, 1869, at 10.30.

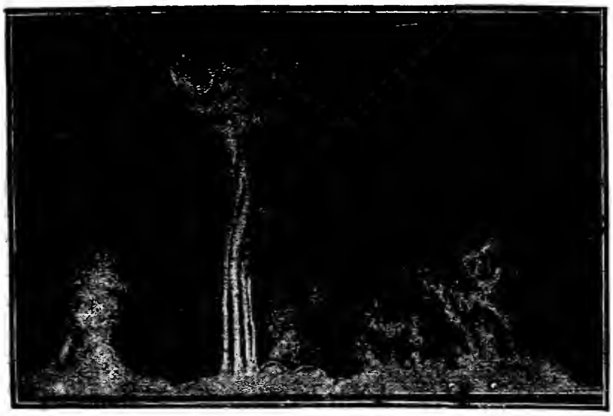

Fig. 4.—The same Prominence as seen an Hour later.

which in an hour could so greatly affect the appearance of this vast volume of flame. The most remarkable observation ever made by this method,

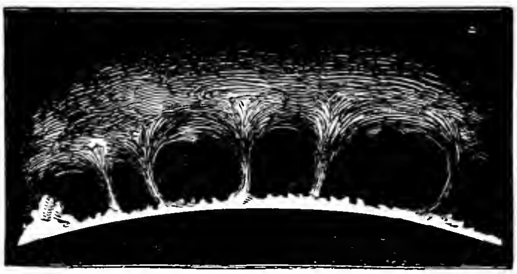

Fig. 5.—A Prominence Cloud seen by Prof. Young, on Sept. 7, 1871, at 12.30.

however, is that illustrated by Figs. 5, 6, 7, and 8.

On Sept. 7, 1871, Professor Young—then of Dartmouth College, now of Princeton, New Jersey—was observing the enormous protuberance-cloud pictured in Fig. 5. It was about 100,000 miles long by about 54,000 in height. He was called away for

Fig. 6.—The same Region at 12.55.

nearly half an hour; when he returned he found to his surprise that "the whole thing

Fig. 7.—The same Region at 1.40.

had been literally blown to shreds by some inconceivable uprush from beneath." The appearance

Fig. 8.—The same Region at 1.55.

was at this time that shown in Fig. 6. He traced these shreds moving upwards till they had reached

a height of at least 200,000 miles, at which immense altitude they disappeared. The subsequent changes are shown in Figs. 7 and 8.

The prominences are seen indifferently round all parts of the sun's disc, very large ones having been seen over the polar and equatorial regions. Yet it is noteworthy that the prominences over the spot-zones are different in character from others. In these zones only are such prominences ever seen as are shown in Figs. 4–8. The large prominences seen elsewhere are always cloudlike, never of the eruptive sort.

It seems also, from observations made by the late Father Secchi, that as the solar spot period progresses, the character of the prominences changes. When there are many spots, large prominences are frequent; when there are few spots or none, large

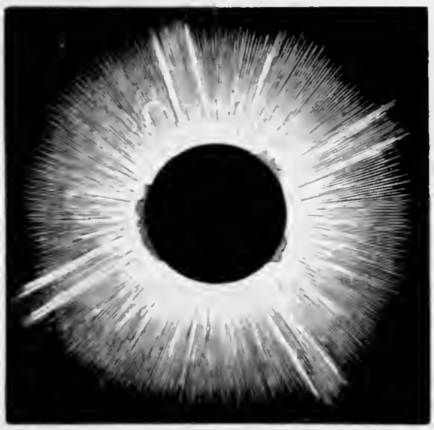

Fig. 9.—The Eclipse of 1842.

prominences are seldom seen, and eruptive prominences of the larger sort are then not seen at all. Some change takes place in the sun's condition—though as yet we do not know what the exact nature of the change may be—which, while causing spots to be either more or less numerous on the sun's surface, causes also the coloured flames to leap higher above that surface, or to sink lower, respectively.

Outside the prominences, a solar appendage far larger in extent can be seen during total eclipse—the so-called corona. Three views of this object as it has been seen at different times, are given in Figs. 9, 10, and 11. They are not arranged in order of date, but in order of complexity of structure. The brightness of the corona is considerable close to the edge of the moon, but gradually becomes less and less outwards, until the light is lost in the sombre background of the sky. The colour has been variously described by different observers, even of the same eclipse. Probably it depends in

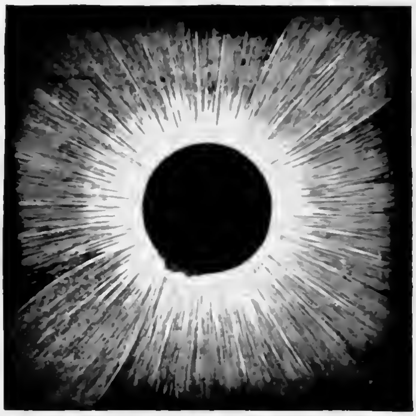

Fig 10.—The Eclipse of 1860 (Feilitzsch).

part on the state of our own air, through which the corona is necessarily seen.

This remarkable appendage was for a long time a source of perplexity to astronomers. If it really belonged to the sun, then, even as shown in the figures, it would have an extension of at least a million miles in some directions, and not less than 800,000 miles anywhere. The volume of the region of space occupied by the corona would be not less than thirty times that of the sun, or more than thirty-seven million times that of the earth. It was natural that many should prefer the less startling explanation involved in the theory that the corona does not belong to the sun at all, but is either a phenomenon of our own atmosphere, or

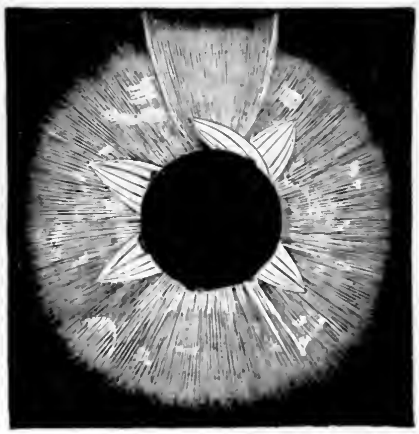

Fig. 11.—The Eclipse of 1858 (Liais).

else is due to the illumination of some vaporous matter surrounding the moon.

But it could be shown conclusively that if the air

towards the sun's place in the sky were illuminated during totality, the illumination, instead of increasing towards the sun, would diminish; moreover, the corona, if that theory were true, should be always changing, and should be entirely different as seen from different stations. Now, during the eclipses of 1870 and 1871 the corona was photographed. In 1870 an excellent photograph was obtained at Xeres, in Spain, by Willard, and a still better one—in fact one of the finest yet obtained—by Brothers, of Manchester, at Syracuse. These agree in such a way as to dispose entirely of the atmospheric theory, even if it were not utterly disproved by the way in which the corona's lustre increases near the sun. During the total eclipse of 1871 in Southern India, a still more complete success was achieved by photographers. For at Baicull, near the shore, a series of six fine photographs was obtained by Mr. Davis, who superintended the photographic arrangements of an expedition sent out by Lord Lindsay, while Colonel Tennant, stationed on the Neilgherries, at Ootacamund, 10,000 feet above the sea-level, obtained also six excellent photographs. All six of Davis's series agreed closely together, though some of course were better than the rest, and showed the corona with a greater extension. All Tennant's views agreed closely together, and, lastly, the views of one set agreed closely with the views of the other set. No doubt then could any longer remain that the atmospheric theory of the corona is erroneous.

With regard to the lunar theory of the corona, which, strangely enough, had commended itself to astronomers so well known as Mädler, Airy, and John Herschel, the photographic evidence of 1871 disposed completely of that theory also. For if the sun's rays by shining on matter around the moon, or on one side of the moon's path, produced the coronal rays, it is quite clear that as the eclipsing moon passed onward the long rays would shift remarkably in position, and all the details of the corona would change rapidly. The circumstance, then, that six views taken at different times during totality agreed exactly together, is a fatal objection to this theory of the corona. The evidence being given in duplicate on that occasion, was yet further strengthened.

It remains, then, that the corona should be recognised as a solar appendage, strange and stupendous though the thought may seem that an envelope of such amazing extent should surround the sun at all times, and yet show no sign of its presence, save when the sun himself is hidden from our view.

The light of the corona has been examined with the spectroscope. The spectrum seen is twofold, if not threefold.

First, there is a spectrum indicating gaseity, a portion of the corona's light giving simply a green line. The position of this line has been very carefully noted. It was at first thought to agree exactly with one of the lines of iron, but recently it has been shown that the iron line is in a slightly different position. At present, no terrestrial element is known whose spectrum has a bright line agreeing exactly in position with the green coronal line. It may be well to mention that the line is generally called "1474 Kirchhoff," because it agrees with the part of Kirchhoff's spectral scale which is thus numbered. This gaseity seems limited to the brighter part of the corona, called sometimes the inner corona, and extending on the average about 300,000 miles from the sun's surface.

Secondly, the corona seems to shine in part with light, indicating glowing solid or liquid matter. For several observers assert confidently that the corona has a perfectly continuous rainbow-tinted spectrum, when examined under such conditions that dark lines, if any exist, should be seen. It might well be that parts of the corona nearest the sun may consist of meteoric and cometic matter, which the sun's intense heat causes to glow with inherent lustre.

But thirdly, as other observers have recognised the solar dark lines in the spectrum of the corona, it seems to follow that other parts of the corona, or even these same parts in some degree, shine by reflecting sunlight.

It should be added that during the eclipse of July 29, 1878, Edison, the celebrated American electrician, succeeded in obtaining clear evidence of the emission of heat by the corona. A very delicate heat-measurer of his invention, called the tasimeter, was brought into action on that occasion; and though Edison was not able to measure the heat of the corona, he obtained unmistakable evidence of its existence. Indeed, he was only prevented from measuring that heat by its being so much greater than he expected. The index which was to show, by pointing to some part of a scale, the exact amount of heat received from the corona, went off the scale altogether so soon as the corona's heat fell on the tasimeter. Before the index could be brought back again to the scale, the sun had reappeared.

During the same eclipse it was shown that the corona ordinarily seen is in reality but a small part

of the real system of appendages existing outside the sun. For by observing the eclipse from stations high above the sea-level, Professor Cleveland Abbe, of Washington, was able to trace the coronal streamers to a distance of ten sun-breadths, or at least 5,000,000 miles from the sun; while Professors Newcomb, of Washington, and Langley, of Pittsburg, traced the coronal luminosity along the zodiacal region, to a distance fully twice as great.

There can now be no doubt that the light called the zodiacal, which is seen in autumn mornings and spring evenings near the sun's place below the horizon, growing brighter towards him, is the outer part of the appendage whose brighter core Newcomb and Langley traced to a distance of 10,000,000 miles on that occasion. But the zodiacal has been traced to a distance of 90,000,000 miles from the sun, and probably in reality has a far greater extension.

Thus, the various solar appendages have been traced outwards from his surface, through his lower complex atmosphere first, then to the sierra, then to the prominence region, then to the brighter corona, to its fainter outer portions, to its far-extending streamers, onwards into the core of the zodiacal, and thence into regions of sun-surrounding space whose real extension is unknown, but may possibly have no limits within the orbit of the remotest planet, Neptune.

To sum up:—We find in the sun—regarded as fire, light, and life of the solar system—an orb glowing with 140 times the intrinsic lustre of the lime-light, and emitting in every second of time as much heat as would result from the burning of 11,750 millions of millions of tons of coal. This vast fiery mass is surrounded by vapours, among which we can recognise, by means of the spectroscope, many of our familiar elements. Such elements as iron, copper, and zinc exist, then, in the form of vapour in the solar atmosphere; yet, intensely hot though we know they must be, they are cooler than the surface above which they lie, since their presence is made known by their dark lines in the spectrum. Some other elements, including oxygen and nitrogen, seem to be so heated as either to show bright lines, or to show no signs of their presence, because neither much cooler nor much hotter than the general surface of the sun. Studying the sun's surroundings, we find his complex atmosphere to be some 300 or 400 miles deep, the sierra from 6,000 to 10,000 miles deep, the prominence region about 100,000 miles deep, though occasional outbursts to twice that height have been observed. The inner corona seems to be some 300,000 miles, the outer about 800,000 miles, in height, measured from the sun's surface. Lastly, there are coronal streamers which have been traced to a distance of 5,000,000 miles, but may in reality extend much further; while the zodiacal, traced in eclipse to a distance of 10,000,000 miles, and during morning and evening twilight to nine times that distance, occupies in reality, most probably, a region co-extensive with the solar system itself.

A FISH IN THE WATER.

By W. A. Lloyd.

In the course of a former paper on the saltness of the sea (p. 25), I have several times mentioned vegetation. If we expose water to light, in any of the four glass vessels referred to in that paper, so that it receives continuous daylight, free from hot sunlight, some kind of plant-life will come—not with absolute spontaneity, as that is impossible, because *something* never comes from *nothing*. But the germs of vegetation are everywhere, and need only water and light to co-exist in or upon a suitable place for them to grow, both abundantly and apparently. But they are individually very small—microscopic, indeed—consisting sometimes of a pair of minute valves, sometimes of threads, variously twisted, and so forth. But they are visible to the unassisted naked eye by their vast aggregation, and they grow with very great rapidity when the conditions of growth are present. I have never been able, as I have said before, to mix any sea or fresh water together in any proportion, without getting vegetation on exposure to light at any temperature above freezing—or say, within the degrees of from 40° to 90° Fahr. For example, we allowed the sea-water (Fig. 5, p. 33) to evaporate, and did so purposely, removing the cork so that its fresh water might escape in part, and leave the remaining solution somewhat stronger than as it is found in British seas. For this purpose, I placed

it a few feet from a window in summer, having a western aspect, so that I might watch the water decrease to a certain mark I affixed to the tube. And while I thus watched the water sink about a quarter of an inch or so, as it did in a week, little patches of green were noticed forming, and growing on its sides, and on magnifying these about 200 diameters—which is, of course, $200 \times 200 = 40,000$ areas, or times—the green was found to be composed of millions of minute plants, and with them were associated millions of minute animals. In fact, the tube had been in a week converted into a little aquarium of a perfectly self-sustaining kind. That is to say, germs of plants previously existed in the water, and exposure to daylight stimulated them to visible multiplication. Contemporaneously with the increase of the plants, came increase of animals, also from germs in the water. And, as far as experience goes, germs of both plants and animals of these minute kinds exist everywhere—in the air, as well as in water—and are only waiting for the requisite conditions to be brought about to grow, and multiply, and become seen. However, as the plants grow, they require food—carbonaceous food, they and all other vegetation being chiefly formed of carbon—and this food they obtain partly from the carbonic-acid gas found in the atmosphere in contact with the water, and partly, and more directly, from the carbonic-acid gas evolved from the minute creatures in the water, associated and in contact with the minute plants. Then, similarly, these minute aquatic creatures require food, and this they obtain, partly from feeding on each other, and partly, and in a lesser degree, from eating the minute plants in the tube with them. Further, as they feed, they give out carbonic-acid gas, as already stated; and if allowed to accumulate in the water, this gas would quickly kill them by poisoning. But it is not suffered to remain, as the vegetation takes up the carbon of it, and sets free the oxygen gas, the other ingredient of which carbonic-acid gas consists. This oxygen is the very thing required by the animals to enable them to assimilate their food and to keep them and their water in which they live in a healthy condition—the water being merely an indestructible compound or medium in which all this takes place. In this manner is kept up, in a wonderful manner, a balance of existence; and I have chosen to show it in this manner, on so small a scale, because it actually occurred quite recently in the very tube figured on p. 33. This, however, requires to be explained—namely, the circumstances governing this minute aquarium were (to use a form of words which is convenient, rather than strictly correct) *self-selected.* That is to say, I did not knowingly introduce any plants or animals. They came by what we call *chance.* But we only say they *chanced* to appear because we do not know, and can never probably tell, the complex influences governing them. In this small glass tube, certain vegetable and animal organisms appeared and disappeared again and again, in obedience to some mysterious law, or sets of laws, which we can only guess at as, remotely, being results of light, temperature, alternations of day and night, varying amounts of substances in solution, and so on. But the organisations come and go, and certainly not adventitiously. If we were to introduce intentionally some living organisation into the tube (Fig. 5, p. 33), we should at once disturb the interchange going on between those already in it, and new arrangements and changes would be set up, leaving ultimate influences which we could not calculate upon beforehand. The quantity of water seen represented in Fig. 5, p. 33, is a little over 1,000 grains weight, there being 437·5 grains to one ounce of sixteen ounces to a pound weight, which latter, therefore, contains 7,000 grains. But 1,000 grains is a quantity of water inconveniently large for my space, and is needless; so I use 250 grains weight of water, in tubes which are therefore smaller than Fig. 5, p. 33. These tubes are of hard German glass, in which water can be safely boiled, and being very thin, anything adhering to their sides interiorly can be examined with a Coddington lens, which gives a tolerably high magnifying power. I have many dozens of such tubes under experiment on a table close to a window with a northern aspect, where the temperature is always between 60° and 70° Fahr. at all seasons, and where the daylight is very equable, with scarcely any sun. The tubes are arranged in small open wooden stands of six each, and this enables them to be shifted about to various parts of the table, to obtain a greater uniformity of exposure to light than if each were fixed in one spot immovably. What I do with these tubes is this:—In some I place sea-water of the full British specific gravity, ranging from 1·027 to 1·030. In others I put sea-water mixed with fresh water, indicating specific gravities from 1·003 to 1·020. Some contain sea-water highly concentrated by boiling. There are three or four tubes belonging to the same denomination, always. Each tube is closed at its mouth with a tight plug of new white cotton-wool, previously well baked to destroy any organic germs it may contain, and is

then firmly tied over with compact white paper, and labelled with a number in two places, the number corresponding with a description of the contents of the tube in a book. The cotton-wool plug, being porous, permits of a restricted contact with the external air, in a manner more accurate than a cork would do, and yet evaporation is almost entirely hindered. In all tubes which have not been boiled, vegetable and animal life in abundance have quickly formed, no matter what the specific gravity may be. In those which have been boiled, and have been allowed to get cold, and then ten grains weight of any unboiled water, sea-water or fresh water, have been added (of course before the cotton-wool plug has been inserted), vegetable and animal life have also appeared. But, in every case, without any regard to the amount of solids dissolved in the water, when the boiling has taken place after the insertion of the plug, so that the steam first drives out through the plug the air which is between the surface of the water and the plug, and when the steam comes freely through the wool, and when the tube is tied over with paper, then I have never found any plants or animals appear on any exposure, because, though there is a certain amount of contact of air with water, no air can gain ingress save what is filtered through the tightly-compressed mass of wool. But, if the wool be withdrawn for an hour, and then replaced, that free contact of water and air of sixty minutes' duration has sufficed to convey germs to the water, and plants and animals make their appearance in a few days afterwards, the tube being thus converted into a small aquarium. I have distilled water directly into a tube from the orifice of a glass retort, without allowing it to go first into another vessel; and though it was plugged immediately the 250 grains were passed over, yet the water had cooled sufficiently not to kill some germs which it must have received from the atmosphere in dropping through it, and in being exposed to it; for in this case, too, plants and animals appeared in due course, as they did not when the water thus distilled was kept, by a gas-flame outside the tube, at a temperature of 200° Fahr. during the process of distillation, and while being plugged and tied. But here, again, in this case as in others, vegetable and animal life appeared on the tube being temporarily unplugged. Precisely the same results were attained with sea-water—not procured from the ocean, but compounded far away from it, both with distilled water, and ordinary London and Birmingham river or well water. Indeed, my conviction as to the use of sea-water for aquaria far from the sea, increases in the direction of being sure that the conveyance of it *far* inland from the coast is a mere waste of money. Roughly stated, one gallon of the strongest British sea-water which can be obtained, weighs 10lb. 6oz., out of which 5oz. are common table-salt (chloride of sodium), and the other ounce is made up of salts easily purchasable and inexpensive, and all can be dissolved, some with rather greater difficulty than others, in all ordinary fresh water. Consequently, when sea-water from the sea can be had at a price less than the cost of the 10lb. of fresh or nearly fresh water, added to the cost of the 6oz. of salts, there can be no need to manufacture sea-water. But, when the contrary is the case, there can be no necessity to incur the expense of conveying water from the sea, at a cost, according to distance, varying from twice to ten times the expense of manufacturing it. And there may be places at such a distance from the coast where the water got from the sea, and that which is compounded, may be exactly equal in cost, while they are equal in their value for aquaria. But we must not reject artificial sea-water (so-called, and a little vaguely so called)—though all sea-water was gradually compounded in course of time by the washings-out of the land, and chiefly rocks of the land—from any *prejudice*, but only from a *reasoning* examination of it, seeing that it can be mixed with great accuracy, and that plants and animals will grow in it. In fact, as it cannot be too repeatedly said, I have never been able to make any mixture of sea and fresh water, whether dipped from the ocean or mixed inland—or whether the fresh be taken from any natural source, or distilled—in which both plants and animals will not appear quasi-spontaneously. Consequently, in the large aquarium arranged under my care near Birmingham, its 200,000 gallons of sea-water are prepared on the spot, and therefore not brought from the sea at all.

I have thus shown that we are sure to get vegetation in water which is exposed to air and light at all ordinary temperatures. The tendency of vegetation to appear is very extraordinary; and so common and universal is plant-life everywhere that we are apt to overlook and disregard it. But the necessity for it is obvious when we remember that, if it were not for its prodigiously large existence, no animal could live. In the absence of vegetation, or of enough of it, carbonic-acid gas would so accumulate in our atmosphere beyond the small quantity which is needed in it (which is about 1 part in 2,500 parts), that all animals, man included,

would speedily die of suffocation. Hence, plants are ever taking up and fixing the carbon out of the carbonic-acid gas which all creatures exhale, building it up harmlessly in the plants, and letting the beneficial oxygen go, to be again used by the creatures to decarbonise their blood, or other vital fluids. This, therefore, is why plant-life grows everywhere—not only as great trees, and other high-growing forms of plants, but as grass, and as such lowly-organised vegetation as mosses, and lichens, and algæ—the latter inhabiting sea and fresh waters. And of all the plant-life grown upon the surface of our globe, and beneath the surface of its waters, the quantity planted by the hand of man is so extremely small in comparison with what appears by what we term chance, or fortuity, that no figures can express the minuteness of the proportion. In fresh water as it exists in rivers and lakes, no forms are ever manually planted, or almost none. In a few ornamental ponds a few such forms as lilies are occasionally grown and tended, but in the "great and wide sea," absolutely *all* grow spontaneously. And in all cases, the carbon which mainly goes to build them up, is primarily obtained from animals, by their breathing. All wood was got, in great part, in this manner. I will confine myself to the railway which passes the house where I am writing this, and will vainly try to imagine what must have been the enormous number of animals whose exhaled breath was converted into the massive, thick timber planks, or rather blocks, termed "sleepers," which transversely support the iron rails at short intervals. More than that, even the fuel which fused the iron which made the rails was once timber, converted into coal or coke; and it, again, was once carbon obtained from the sent-out breathing of animals. And here comes a train of carriages swiftly borne along these rails. All the wood in those carriages was grown from the same source. All the metal in them was smelted and wrought by burning fuel obtained from the same source. More than that—the very power which moves the train along was mainly obtained from the same source. That is to say, the fuel which is being burnt in the furnace of the locomotive engine, which boils the water, which raises the steam, which presses the piston backwards and forwards in the cylinders, was once wood, and that wood was derived from the breathing of animals.

But this very curious persistence of growth which vegetation has, shows itself in aquaria in a very inconvenient manner sometimes. Thus, if a vessel of water, more especially sea-water, be exposed to a strong light, accompanied by a somewhat high temperature, for a considerable period, seeds or spores will appear in the water to such an enormous extent that they will make it turbid, and finally densely opaque. These spores are only about $\frac{1}{2000}$th of an inch in diameter, and are locomotive; hence they distribute themselves all through the fluid. I have known water made so densely greenish-brown by these organisms that I have not been able to read large print through two inches of it. The best and only known way to avoid this, is by reversing matters—that is, by placing such water in darkness. This would be inconvenient—such darkening of an entire aquarium—and therefore *a part* of the water is allowed to be in the dark, as shown in this ideal vertical section (Fig. 1). Then, a

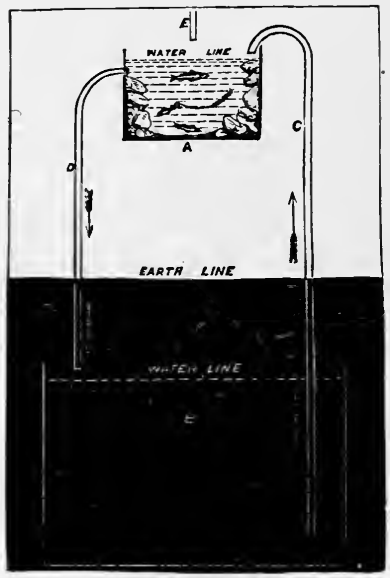

Fig. 1.—Ideal Vertical Section of an Aquarium.

circulation is set up between the light and the dark portions. A is the light portion of the system, B is the dark part. Between these two, water circulates through the pipes C and D, and E is a pipe furnishing distilled water obtained in any convenient manner. B is here shown below the ground, but it may be in any other place so long as the two essential conditions of darkness and coolness are complied with. The arrows show the direction of flow. This plan of arranging aquaria, whether sea or fresh-water, is the best known one, because it most nearly represents what is everywhere done by Nature. The greater part of all water on the face of our globe is in utter darkness, and thereby the excessive dissemination of algæ spores which I have

explained, is prevented. And the greater part of all water in a state of nature is kept cool by being kept out of the direct influence of the sun. So, in like manner, the animals intended to live in such water are adapted for a temperature which, in temperate countries like Britain, is not so high as the maximum temperature of its air, nor so low as its minimum. Hence, in Britain, the best temperature for water in aquaria is about 60° Fahr., and this degree may be easily maintained in the hottest summer and in the coldest winter of our country, by care in the selection of the situation of B. And the larger B is made in relation to the size of A, the more equable will be the temperature of the whole, and the quicker will be the decomposition of decaying organic matters given off from the animals by being resolved into their primary and harmless constituents. B should be from 3 to 5 times as great as A, but if from 6 to 10 times, so much the better. Indeed, it cannot be too large. The amount of distilled water admitted at E must be regulated by circumstances, remembering that in dry air, at a temperature of 60° Fahr., evaporation takes place at the rate of about 2 to 3 grains' weight of water for every space of 6 square inches of surface every day of 24 hours; this being increased when the surface is extended by motion, as in such an aquarium as this represents. And such motion, and such extension of surface, signify increase of oxygenation in proportion; and oxygenation means the burning up, or consuming, or getting rid, as quickly as they form, of all decaying organic matters, which, not so consumed, would poison all creatures brought within its influence.*

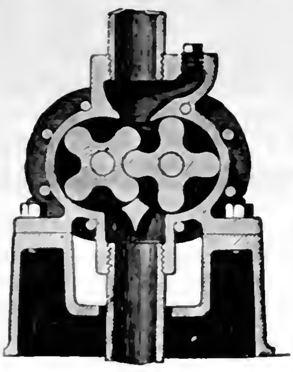

Fig. 2.—Forbes's Vulcanite Pump for the Circulation of Water. (*One-tenth actual Size.*)

I have not shown any means of circulating the water in Fig. 1, it being on too small a scale; but Fig. 2 gives a vertical section of the form of a pump which I have found the best one, and, indeed, the only good one. It is known as Forbes's patent, and consists of two rollers, each with four projections accurately fitting into the opposite hollows of its neighbour, and the water is *rolled through* these, so to speak. This is a very simple arrangement, working with but small friction and wear, and at a moderate speed. The motive power may be hand, or steam, or water, or gas, &c. Or wind-power may be employed very economically; only, in such cases, another and upper reservoir is needed in addition to B, so as to be used when there is no wind to drive the pump. It would be easy to contrive an automatic valve which shall open without manual attendance when the pump ceases working. All such pumps, pipes, &c., should be made, whether for marine or fresh-water aquaria, in vulcanite or ebonite, or hard indiarubber, to avoid the mischievous oxidation of all ordinary metals, as iron, brass, tin, lead, &c. In smaller aquaria, such as are used in private houses, where it is not desired to have any contrivance of pumps, pipes, &c., a reservoir of stoneware may be used; and one (Fig. 3) is here engraved, provided with a stop-cock of the same material. When such a vessel of 50 gallons is used to occasionally refresh an

Fig. 3.—Stoneware Water Reservoir. (*One-tenth actual Size.*)

* This burning at a low temperature was called by Baron Liebig "eremacausis."

aquarium of 12 gallons, its value is very great, especially in hot weather, when the reservoir may be kept in a cool cellar. To use it, draw from it, say once daily, about three or four or more gallons, into an earthenware jug. Syphon as much from the tank, and then exchange the two waters. In this manner—at any distance from the sea, if the aquarium from the sea, or from fresh-water sources, continually. At the aquaria of Brighton and Scarborough there is no such circulatory arrangement as in Fig. 1, but the water is very imperfectly aërated by a current of air-bubbles driven by a machine from a tube opening at the base of each tank. The incomplete and too slow oxygenation of

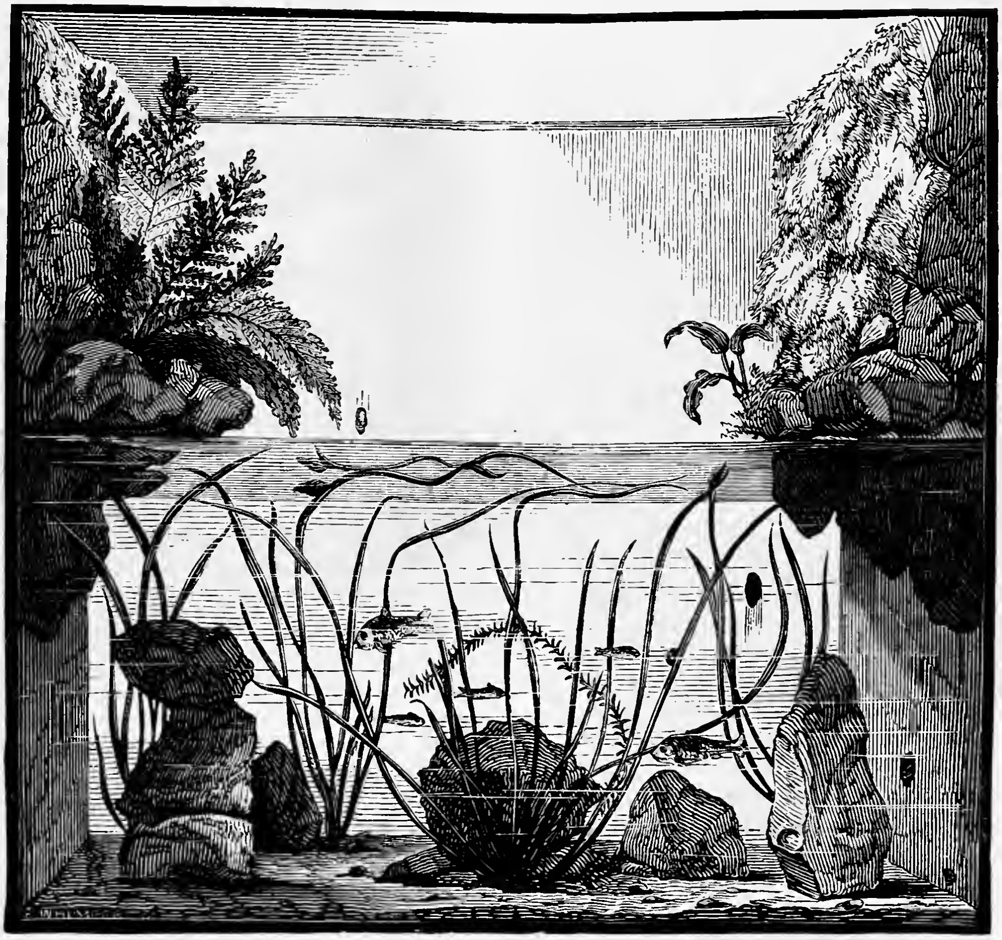

Fig. 4.—The First Known Flat-sided Aquarium. (*One-fifth actual Size.*)

is marine, and at any distance from any supposed want of a supply of sufficiently good ordinary water, if the aquarium be fresh-water—a constant current may be obtained, day and night. Indeed, all the best large public marine aquaria, even at the borders of the sea, are those where the water is never changed, but ever circulated after the manner shown in Fig. 1, as it is found that water which has been once made clear and good, and maintained in a respiratory state for the animals, is better and clearer than any water newly pumped decaying organic matter which this mode results in, necessitates the water being changed occasionally, and this, and other labour incurred in the manual cleansing which such a mode implies, causes it to be a very wasteful and unscientific plan.

The annexed wood-cut (Fig. 4) shows, from the original block, a figure of the first known aquarium with flat sides. It was constructed in the spring of 1849, for its proprietor, Mr. Robert Warington, an eminent chemist who lived in Apothecaries' Hall, London, and who kept it there, with

unchanged water, from the period above named till his death, in 1867. It had a slate base, slate ends, and two opposite sides of plate glass. It measured, interiorly, 24 inches long, and 18 inches broad. The water-space was 12 inches high, and the contents here shown were all carefully drawn to scale. A fresh-water aquarium is represented, but the same proportions of plants and animals would suit a marine one. The vegetation shown immersed in the water is chiefly *Valisneria*, with long, strap-like leaves, and there is one plant of *Anacharis* (*Elodea*, Vol. I., p. 300). None of these were really wanted, however, because, on exposure to light, sufficient of the lower forms of vegetation, as *Conferva*, &c., would have grown quasi-spontaneously, as explained. Had it been a marine aquarium, doubtless, in less scrupulous hands than Warington's, a goodly number of the higher sea-water plants, belonging to the green, red, or brown series, would have been shown growing in the tank, after the fashion of some so-called "popular" books on the aquarium. Personally, I would give very much if I knew how to cultivate at will, as one grows flowers in a garden, any of the higher marine algæ, especially the beautiful red kinds or *Rhodosperms*, or even *Melanosperms*, or the larger *Chlorosperms*. Occasionally I have grown one or two, at rare intervals, never by skill, but always by chance; and as I have never known *why* I so grew them, I have never been able to repeat the success intelligently. In Warington's picture several plants, being moisture-loving ferns, are shown growing on the rock-work in air, above the water. These forms of vegetation, however, have no *direct* influence on the maintenance of the water below in a respirable condition for animals which take their oxygen from what is contained dissolved in that water. And this brings me to an important point—namely, the introduction, according to a too frequent practice in recent periods, of animals breathing air by lungs, into aquaria. Such animals, like all others, certainly demand the influence of plants in decarbonising the air which they have respired, but they do not, save in a very *remote* degree, which cannot in any aquarium be taken into account, need to have any water in which they move or swim, aërated for their breathing of it, because they do not breathe it: they breathe atmospheric air. Their lungs consist of a mass of little cavities which air *enters*, whereas gills consist of filaments which aërated water *surrounds*. When Milton says of a whale that it—

> "At his gills takes in,
> And at his trunk lets out, a Sea,"

he makes four mistakes, in spite of the beauty of his language: (1) in saying that the animal has gills, whereas it has lungs; (2) that it takes in water, other than in the form of aqueous vapour, which is not the spirit of the description; (3) that the whale ejects water by "spouting," as described and usually shown in pictures; what the creature really does is, by the force of its expiration, to drive up into the air whatever water may be between its blow-hole and the surface of the sea; and (4) that such moisture as the animal takes into its body is necessarily sea-water.

But, in truth, there is not, and can never be, any complete separation of influences, such is the wonderful inter-dependence of all organisms in nature. Thus, the tiny moss which so gladdened the eyes of Mungo Park when depressed in spirits and alone, amidst the sands of equatorial Africa, hundreds of miles from the sea, was really dependent on that sea; and the moss, moreover, contributed its share—minutely, it is true, and in a very indirect manner—in maintaining that sea in a condition fit for the sustenance of other beings.

I cannot end this paper better than by recording a marvellous instance of the persistence of vegetable life, which has come under my own notice, and the circumstances of which have been brought about by my own hands. On October 6th, 1870, I placed 2,000 grains of clear sea-water in a glass bottle closed with a ground-glass stopper, tied over with oiled silk, and then wrapped it in two thicknesses of brown paper, afterwards inclosing the whole in a tin case with a cover, and finally tying up the whole in brown paper, and labelling it. A week ago—this is written on September 4, 1878—I unpacked the parcel, and found the water perfectly clear, and free from smell, and of the same quantity as when I inclosed it. And, after exposing it for one week in a window having a northern aspect, an abundance of microscopic vegetation has already grown on the base and sides of the bottle. Concurrently with the plants, have also come swarms of microscopic animals. Therefore the germs of these plants and these animals must have been in the water, in a state of arrest, for nearly *eight years*, and they came into visible existence on being exposed to light for scarcely *eight days*. Most assuredly, I never introduced any germs, intentionally, into the bottle, for I was too anxious to have so rare a chance of verifying what I believed would be the case *theoretically*, but which I wished to prove *practically*.

A MICROSCOPICAL BIOGRAPHY.

By W. Henry Kesteven.

If some of the greenish scum of stagnant water, taken during the autumn months, be placed under the microscope, the colour will be found to be due to the presence of numberless specimens of a certain animalcule.

This is the *Euglena viridis*, a minute creature, belonging to the Infusoria, members of the lowest group of the animal kingdom. Under low power, these animals are seen to consist of cigar-shaped,

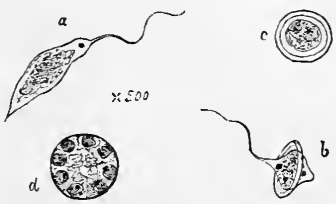

Fig. 1.—Euglena viridis. (*Magnified 500 diameters.*)

(*a*) Euglena as seen when moving rapidly; (*b*) Through-the-Hoop Movement; (*c*) State of Rest; (*d*) Segmentation.

cylindrical masses of greenish jelly, or, more correctly, "sarcode," one remove from protoplasm, a substance found alike in plants and animals (Vol. I., p. 340). Sometimes they appear perfectly spherical. In the former state they move rapidly about the field of the microscope, revolving at right angles to the direction in which they travel. In the latter, or spherical, condition they are quite still, and are said to be at rest. In addition to the above method of locomotion, they possess another and a more peculiar (Fig. 1).

An individual will pause suddenly in its rapid whirling progress, and will apparently attach itself by its tail or posterior extremity to the glass. Making this attachment act as a pivot, it slowly and gracefully waves round and round, with its body still elongated. In this state it will remain for several seconds, and will then either detach itself suddenly and depart rapidly with its former motion, or it will gradually assume a spherical form, contracting its front and hinder extremities towards the middle portion of its body. This bulges at right angles to its axis till it has assumed the form of a perfect disc. In this shape it slowly revolves in a hoop-fashion once or twice, sufficiently, at all events, to make it a matter of doubt as to which is the anterior and which is the posterior side of the disc; it will then slowly elongate itself again: the effect of the whole process being to produce the appearance of making itself into a hoop and then walking through itself.

Under the higher powers of the microscope these movements are seen with greater accuracy, and certain other points in the anatomy of the animal become manifest. Thus, its front extremity or head is seen to be rather a complicated organ. It has one red "eye," or eye-like spot, situated about one-eighth of its entire length distant from its anterior extremity. It has also a very curious organ, which it uses both for locomotive purposes and presumably for the purpose of collecting or catching its food. This is a long, thread-like filament. In length, this filament sometimes equals that of its body. It is exceedingly fine, and, having a very rapid movement, is very difficult to see. In fact, except when the animal is in a partial state of rest, or gently revolving on its posterior extremity, this organ cannot be detected. When in the state of complete rest, it is folded up in such a manner as to render it invisible. This state of rest seems to be assumed for two purposes, and under different circumstances. It may be assumed apparently with no other purpose than that of procuring rest; for at times, after remaining in this condition for an indefinite time, the animal will slowly revolve and again start on its peregrinations, generally commencing with the slower, or through-the-hoop method described above, and then suddenly starting off, much after the manner of a bullet from a grooved rifle-barrel.

The state of rest is also assumed for another and more important purpose. These animals, as they reach a certain age, somewhat change in appearance. Instead of being of a uniform brilliant green tint, the green colouring matter becomes divided, leaving intervening spaces of colourless material. Shortly after this has taken place, the animal settles down into a state of rest: that is, it assumes a fixed spherical form. This condition may, under these circumstances, be considered as the death of the individual as an individual. The green particles collect in the centre, apparently forming one mass, and leaving a circumference of colourless material. This becomes divided into two or three zones, apparently forming a sort of cell-wall or envelope, in which is confined a small, spherical, green, moving mass. The movement of this mass is intermittent, and consists of

revolutions, first in one direction, then in another. After some further interval of time, a further change takes place; the green mass divides into a variable number of smaller masses, some larger, some smaller, the appearance of zones in the envelope disappears, and the green masses gradually approach the circumference. In this position they are developed into perfect individuals, and after a time, rupture of the cell-wall taking place, they escape as such.

To ascertain the periods of time thus consumed in the different steps of the life-history of this interesting animalcule, it would be necessary to watch an individual throughout its existence. This is a matter of great difficulty, for the reason that the lifetime which has to be observed lasts longer than the small drop of water in which the animal is living on the slip of glass under the microscope; and as their extreme length, when at their largest, does not exceed the 100th part of an inch, it will be readily understood that it is not possible to watch them except under the microscope.

The life-history, as above described, has been made out from numerous specimens, exhibiting the different stages of growth and reproduction.

FIRING A SHOT.

By H. Baden Pritchard, F.C.S., of the Royal Arsenal, Woolwich.

We have from time to time heard so much of the doings of big guns that it is well worth a moment's reflection to consider what is involved in the operation of firing a shot. In the early days of the "Woolwich Infant" it was avowed that every time that 35-ton piece of ordnance was fired a ten-pound note was blown from the muzzle in the shape of powder and projectile; and now that we have 80-ton weapons which fire bolts of three-quarters of a ton, and as much gunpowder as is represented by a sack and a half of coals, the cost of a shot has increased still further (Fig. 2). But it is not so much the cost as the physical and chemical aspects of firing that I have here to discuss; and if the reader will lend his attention for a little while, it will be possible, I think, to explain these to his satisfaction.

Most people know what gunpowder is, and how it is manufactured, although none of us can tell from whom we first derived the knowledge. We, in this country, usually point to Roger Bacon as the discoverer of gunpowder; while our German cousins are very firm in their dictum that no other than Berthold Schwarz was its originator. At the same time it is very certain from references found in Arabic and Chinese, that the composition of the explosive was known long before either of those philosophers came into the world. Still, if we are to regard gunpowder as an agent in firearms—and it is important only in this respect, and for blasting purposes—then it can hardly be disputed that the material was, in the first case, employed in warfare in Europe, and the battle of Cressy is usually cited as the occasion on which "villainous saltpetre" was originally used.

In the same way as all attempts have proved fruitless to discover the inventor of gunpowder, so, too, has every effort of ours failed to improve its chemical composition. We use pretty well the same proportions of charcoal, sulphur, and saltpetre in its composition as were in vogue five hundred years ago, and if we have to-day succeeded in producing a more trustworthy and handy product, this is simply because our means of manufacture have been bettered. Gunpowder prepared for warlike purposes is usually made up of

Nitre	75 per cent.
Charcoal	15 ,,
Sulphur	10 ,,

and I may, in a few words, explain how its manufacture is carried on. In the first place the ingredients are very intimately mixed together, and as soon as this is done they are carried off to the "incorporating mill." Here heavy rollers reduce the mixture to a fine powder, and to render the "incorporation" still more complete, a little water is sprinkled upon the mass. This is now termed "mill-cake," and after it has been put under hydraulic pressure, to press it into solid cakes, the name "press-cake," is applied to it. "Press-cake" is gunpowder *en bloc*, and according to whether you want coarse or fine-grain gunpowder, so it is broken up into small or large grains. This fact it is well to bear in mind, since one is apt to believe that the coarser the gunpowder appears, the more coarsely it is mixed; all gunpowders, however, no matter how they appear to the eye, have been thoroughly and intimately incorporated. To give the grains the polished appearance they exhibit they are rolled in a drum, and thus hardened and glazed.

In the case of gunpowder employed in our heavy guns nowadays, the name "powder" is altogether a misnomer. The grains have grown to monstrous size; and two-inch cubes are sometimes employed, weighing half a pound a piece. Pebble-powder, pellet-powder, prismatic powder, mammoth-powder, *poudre-brutale*—the latter not so large a grain, albeit it has proved mischievous enough—are some of the names given to cannon powders (Fig. 1). The reason for this enlargement of the grain is not far to seek. As I have said, the chemical constitution of powder has not varied in any marked degree, but, nevertheless, its burning properties have been placed under considerable control by simply altering

Fig. 1.—Various Kinds of Powder.
(1) *Poudre-brutale*; (2) Pebble; (3) Mammoth; (4) Prismatic; (5) Cube.

the form and density of the grains. When we had smooth-bore guns and mortars to deal with, and a loose-fitting cannon-ball, the main thing necessary in firing a shot was to jerk out the latter with as much force as possible. But if we did this with rifled weapons, we should, in all probability, simply burst the arm, without stirring the shot. In a rifled gun we want the projectile to be gradually brought into motion, and to be impelled by a steady and increasing push. This would not be the result if the old gunpowder were used, consisting of fine grains. Fine-grain gunpowder explodes quickly, and would strain the gun terribly before the shot got into motion at all; what is wanted, therefore, is a slower burning material, and this is secured by having recourse to grains of larger size. A given weight of powder in one mass takes longer to burn than the same weight divided into ten fragments all kindled at once. The less surface there is to kindle, the slower will be the combustion, and as large masses present less surface—weight for weight—than small ones, it follows that large-grain gunpowder must necessarily burn slower than fine-grain. It is for this reason that the grains of gunpowder have grown with the size of our guns. An artilleryman always wants to get the most work out of his gun, and he can only do this by carefully studying the size of his gunpowder. If he has the grains too small he strains the weapon without increasing the energy of the shot; if the grains are too large, they may be still unconsumed when the shot leaves the muzzle, and some of the charge is blown from the gun unburnt. To be brief: in a rifled gun the powder should exert its maximum effect when the shot has reached the muzzle, but not till then. It may appear to the reader, at first sight, a matter of some difficulty to ascertain whether gunpowder does its duty properly in this respect; but as I shall presently show, the way to find this out is tolerably easy after all.

And now in respect to the chemical change which gunpowder undergoes in firing a shot. Gunpowder does not require air for its explosion; it carries oxygen enough—in the saltpetre—to serve for its own decomposition. It can be tightly shut up in a canister and sunk in the sea, and yet be exploded as readily as in the open air. On ignition, the charcoal, or rather most of it, which consists of carbon, "combines" with the oxygen of the saltpetre and becomes carbonic acid in a gaseous state. It is this carbonic-acid gas, added to a large volume of nitrogen, which is also set free on the decomposition of the saltpetre, which supplies most of the elastic force necessary to fire the shot. The gases being suddenly generated in a very confined space, at once expand, and cause the shot to be expelled from the gun, together with all that noise and vibration which are inseparable from the discharge of firearms.

This is not all that takes place in the combustion of gunpowder, for carbonate of potash, sulphate of potash, and possibly other salts too, are formed in the sudden decomposition that ensues on the firing of a shot. The sulphur, for the most part, passes into sulphuric acid, combining with oxygen to do so, and then forms the sulphate of potash of which we have spoken. To send the shot on its rapid flight, it is necessary to generate quickly the largest possible volume of gas in the chamber of the gun, and this is effected by the intimate mixture of saltpetre, charcoal, and sulphur, represented by gunpowder.

But, it may be asked, what is the volume of gas produced, compared to the original space occupied

by the gunpowder? for in that way only can we get an idea of the sudden energy that is generated. This is not so easy to determine, for hot gas takes up much more room than cold gas. In a gun we do not quite know the temperature of the gas at the time of explosion, for as soon as the shot begins to move the gas rapidly cools. In the case of gas at a temperature of 60° Fahr., it is found that one cubic inch of gunpowder yields about 207 cubic inches of gas, at atmospheric pressure. Confined in a small space at the time of explosion, and being, too, at a

all, charcoal, it seems, varies very much in its character. Therefore, although we always add the same amount of charcoal, we do not always get the same result. According to the temperature of charring, and the state of perfection to which this process is carried, so does the percentage of carbon vary, and as there is more carbonic-acid gas than any other generated on the explosion of gunpowder, this point is naturally one to which great importance attaches in these days of arms of precision.

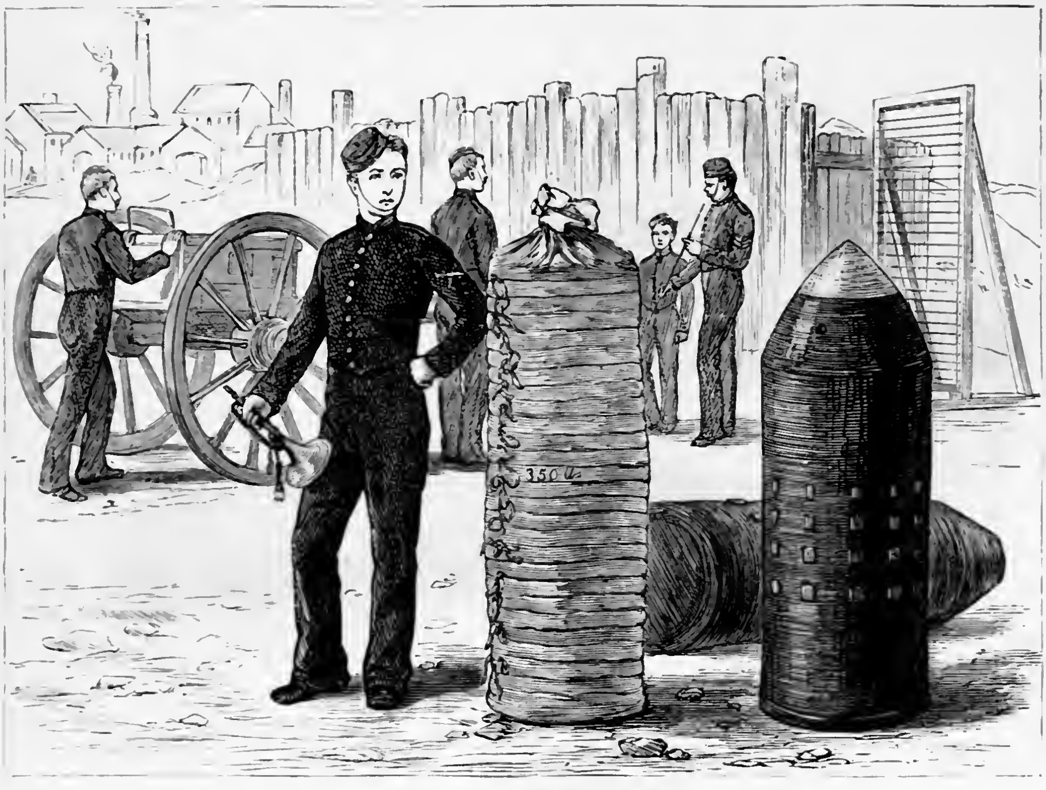

Fig. 2 —Shot of the 80-ton Gun.

very high temperature, it is reckoned, however, that the gas at the instant of firing would occupy momentarily ten times this volume at least, so that, advantageously ignited, one cubic inch of gunpowder expands more than 2,000 times; and this, we are told, is equal to exerting 34,600 lb., or 15½ tons upon the square inch. No wonder cannonballs move through the air at a high velocity.

Before dismissing the chemical aspect of the subject, there is one more point that must be alluded to. Although, as I have said, the proportions of the materials employed in the manufacture of gunpowder practically never differ at

We know now something both of the mechanical and chemical nature of gunpowder, and also of its conversion into gas and the expansion of the latter at the time of firing a shot. We will now go further, and follow the shot in its career. Not too quickly, however, for I wish the reader to fully understand how much we have recently learnt of the doings of the shot both inside and outside the gun. Under ordinary circumstances, I may mention, that a projectile, in one of our heavy rifled guns, takes, as nearly as possible, $\frac{1}{100}$th part of a second in travelling from one end of the weapon to the other. Many will smile, no doubt, at such a

statement; but it is no haphazard guess, as will presently be seen. It is possible, nowadays, to measure with accuracy the flight of a shot to within a millionth part of a second, with the aid of an electric tell-tale, to which its inventor, Captain Noble, has given the name of "Chronoscope."

The chronoscope, too, is an instrument very easy to understand. Inside the gun are fitted half a dozen rings through which the shot passes on its way to the muzzle. The rings are placed at an equal distance from one another, and may be taken to represent so many stations past which an express train rushes at great speed, the projectile being the speed. The grindstone or wheel is of metal, and its outside edge is blackened by allowing the soot or smut of a candle to deposit itself thereon. It is a singular circumstance, that if you have a soot-covered metal surface, and permit an electric spark to hop upon it, the spark flicks away the soot, and a tiny round spot of bare metal is the result where the electric discharge has taken place. This fact is made use of in the chronoscope.

Let us now suppose the blackened wheel of the chronoscope to be revolving rapidly—there are in reality several wheels, but one is enough for purposes of explanation—and that the gun is ready to

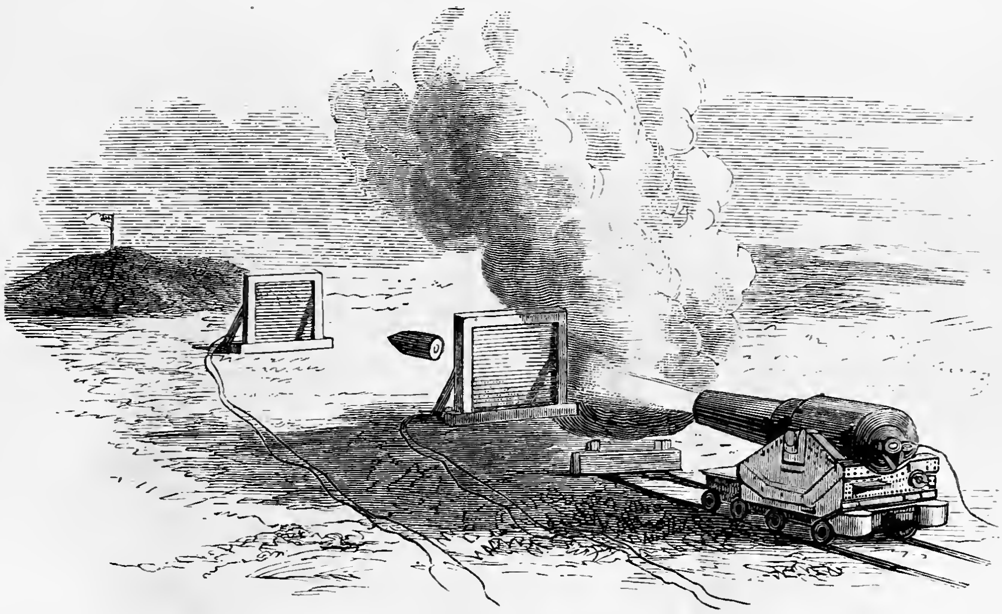

Fig. 3.—Course of the Shot through the Screens.

express train in question. Each station has its own electric signal, whereby the passing of the shot is recorded. Under each ring is a wire, and this wire leads away to the instrument-room where the records are received. An electric current passes along each wire from the gun to the instrument, but when the shot passes a ring it presses the latter down upon the wire and cuts the same. So that one ring after another, as the shot passes by, cuts the wire under it. The effect is of course that the electric currents are also broken successively on one wire after another, and this fact is conveyed to the instrument-room by six tiny sparks coming along the six wires immediately one after another.

In the instrument-room is the chronoscope. This instrument may best be understood by picturing to oneself a fly-wheel or a grindstone rotating at great be fired. Almost touching the rim of the wheel are the ends of the wires coming from the rings inside the gun. Suddenly the shot is fired. The projectile getting into motion immediately passes the first station or ring; the wire underneath is cut, the electric current is instantly suspended, and a spark passing to the instrument-room hops on to the revolving wheel. Number 2 ring, as the shot passes through it, sends in like manner a spark through its wire, and this also makes a tiny spot upon the blackened wheel just after the first spot. And so on with rings 3, 4, 5, and 6, all of which send their respective sparks as the express train, represented by the shot, passes by all the stations.

The shot fired, we stop the rotating wheel, and then find recorded upon it, one after another, six tiny spots. The space between the spots represents

the time which the shot has taken to travel from ring to ring inside the gun. As the wheel has been revolving at a certain specific speed, and as, moreover, we know precisely the circumference of the wheel, it is a mere matter of figures to find out what fraction of time these intervals represent. As I have said, a hundredth of a second is consumed in the case of a shot passing through the whole length of our heavy cannon, but after the shot once begins to move its velocity increases rapidly. This is shown by the records on the chronoscope wheels. If the shot passed all stations at the same speed, the tiny specks of bare metal would be equidistant. This, however, is not the case. On the contrary, the intervals between the records become gradually less, proving that the shot moves very fast as it nears the muzzle.

By means of the chronoscope we can thus tell if a gunpowder does its duty, for the development of energy, whether fast or slow, is at once recorded. Again, when the shot issues from the muzzle, it is possible, by having recourse once more to electricity, to tell precisely the range or penetration of the missile. There is no need for a long practice-ground, or a stout iron target; artillerists now-a-days can tell very well what a shot will do if the proof-butts are within a hundred feet of the muzzle of the gun. This is done by calculating what is termed the "initial velocity" of the shot.

A screen of fine copper wire is erected in the path

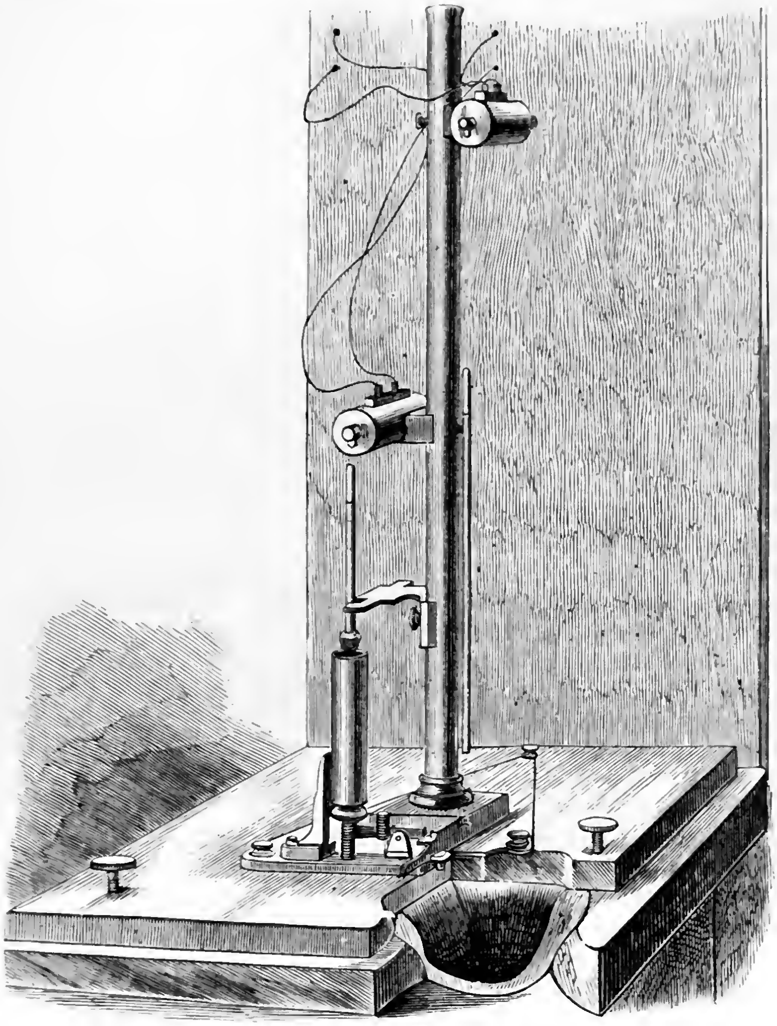

Fig. 4.—Initial Velocity Apparatus.

of the shot, just in front of the muzzle; another similar screen is placed a hundred feet off, also in such a way that the shot will pass right through, as it plunges forward at the outset of its journey. In this way we get the projectile to break Number 1 screen, and to travel 100 feet before breaking the second. In both cases an electric current is passing through the copper wires of the screens, which are connected by other wires to the instrument-room. At the discharge of the gun, the shot therefore is made to break two electric currents one afteran other, as it tears through the screens (Fig. 3).

The recording instrument in this case (Fig. 4) is more simple than the chronoscope. It consists in the main of two magnets, which are magnets, however, only so long as an electric current passes round them. The instant this current ceases, the magnets lose their virtue altogether, and are then nothing more than pieces of iron. We will now imagine that the gun is ready for firing, that the electric current is passing, and consequently that we are in possession of two magnets. From these electro-magnets are carefully suspended two metal rods; Number 1 magnet being in connection with the first wire screen, and Number 2 magnet in connection with the second screen. The shot is fired. It ruptures the first screen. What happens? Why, the first electric current is broken forthwith, and Number 1 magnet has no longer any virtue. The metal rod that has been suspended all this while, consequently falls.

But while Number 1 metal rod is yet falling the shot has travelled a hundred feet, and has ruptured the second screen. Hereupon magnet Number 2 has ceased to be a magnet, and the second rod, which has been hanging parallel to the first, also drops. This second rod in dropping falls upon a sort of trigger arrangement, which causes a sharp knife-edge to dart forth, and this knife touches rod Number 1, which has not yet had time to fall its entire length. Indeed, Number 1 rod, which is about two feet long, has only had time to fall about half its length, when this knife makes its mark, and it is the whereabouts of the indentation upon the rod which tells us how fast the shot is flying. If, for instance, when we pick up rod Number 1, and examine it, we find the abrasion twelve inches up, then it is a patent fact that the rod fell a distance of twelve inches while the shot travelled a hundred feet. The weight of the rod is accurately known, and as the time too is known that a given weight takes to fall a certain distance, the actual fraction of a second is quickly calculated. As a matter of fact, I may say, that a shot such as our "Woolwich Infants" fire, travels through the air at the outset at a speed of something like 1,500 feet per second.

One other means of determining the pressure of gas inside the gun, deserves to be mentioned, since it affords a ready way of ascertaining whether the weapon is being strained or not. For instance, in the 80-ton gun, it has been taken for granted, that any pressure beyond 25 tons to the square inch is injurious to the weapon, and this is the maximum which any powder should be permitted to exert. Both the chronoscope and the initial velocity apparatus tell us something of the pressure, but to make quite sure, a little copper pillar, called a "crusher-gauge" is used. The copper pillar is fitted loosely inside a tube; one end is fixed against an anvil, to prevent it moving backwards, so that when subjected to the pressure of the gas inside the gun, the pillar gets compressed and crushed to a certain extent. In a word, the pillar becomes shorter, and assumes something of a barrel-shape. The "crusher-gauge" is either fitted to the base of the shot, or somewhere in the tube of the gun, where the full force of the gas can act upon it. After firing, the height of the pillar is accurately gauged, and the shorter it is, of course the greater has been the amount of pressure. The exact pressure is at once ascertained by comparing it to other similar pillars which have been subjected to various degrees of pressure.

Thus, firing a shot at the present day involves many considerations and calculations. The employment of gunpowder in firearms is no longer a matter of rule of thumb as in the days of smooth-bore guns and round cannon-balls, and gunnery has of late become a science of itself. We should never have dared to construct monster rifled ordnance, and to employ therein battering charges of several hundred pounds, if we did not all the while know something of what was going on inside the gun.

WHAT IS "POWER"?

By William Dundas Scott-Moncrieff, Civil Engineer.

WHEN the word "power" was first used by our Anglo-Saxon ancestors, men thought very little about science. In those early days the habits of observing the common occurrences of nature had never been acquired. The simplest phenomena were unnoted, and only those events attracted attention which were rare, and only those which were marvellous excited wonder. The fall of an apple must have been noticed from time immemorial, but it remained for the inquisitive of modern times to discover the laws that regulate its descent. Newton and his contemporaries had a method of studying nature which showed that the marvellous was often most easily explained, while the common occurrences of every-day life remained as subjects of inexhaustible interest. The story of the falling apple—apocryphal or not—is an apt illustration of how great things and small are alike dependent upon the laws of the universe, since it is said to have suggested the first conception of the forces which control the motions of the stars; and it is the purpose of the present paper to show how "power," which is a necessary condition of *force* and *work*, is exhibited among the common objects of every-day life. It will be well, perhaps, before going further, to say something of the word itself.

In many cases a word when imported into a special field of usefulness has acquired a meaning peculiar to that particular relationship; as, for example, the word "field," which in this sentence is employed in an indefinite and suggestive form to convey the idea of scope or capacity, but which, as the reader is aware, is also used in optics to convey the meaning of a range or limit of vision. This constantly increasing demand for words to convey precise and specific scientific meanings has been going on for a long time, and has been encroaching upon the ordinary vocabulary of the language until it has become necessary to find new methods of adding to our supplies. To this end all sorts of ingenious devices have been resorted to. For instance, in the measurement of electricity, the words "gallons," "tons," "inches," &c., were manifestly inapplicable, and as the new measurement required a special method, electricians invented some new standards altogether, and killed two birds with one stone by framing a set of suitable words, and at the same time immortalising the great electricians by making their names the foundation of the new terminology. There are several departments of literature to be greatly congratulated upon this effort on the part of Science to shift for herself in the matter of a vocabulary. Generally speaking, it would be an exceedingly bold thing for even the most distinguished masters of a language to invent a word for the ordinary purposes of literature; but no one is ever likely to find fault with scientific men for introducing them to their hearts' content. Every one who has any regard for the integrity of the inheritance we have received in our great and noble English language, will be glad to see it preserved to the uses for which it was originally intended.

Passing now to the particular subject of this paper, the choice of the word "power" has, on the whole, turned out to be somewhat unfortunate, not so much because it is unsuitable for conveying a certain exact scientific meaning, as because a confusion of ideas had already arisen from its being misapplied to certain uses which science showed afterwards to be inconsistent with the best application of which it was capable. The word originally was, no doubt, used in very much the same sense as "strength," with which it has a very remote scientific connection. A distinction is apparent, however, even in the popular application of the two words, "power" and "strength," when we find the first used in such a connection as that of "water-power," or "wind-power," because here a person of the most ordinary intelligence can distinguish between that sense of capacity for work which is conveyed by the word "power" as contrasted with the idea of repose which is given in "strength." This distinction has found its development in two distinct sciences—"statics," the science of material repose; and "dynamics," the science of moving energy.

As an illustration, we will now notice the broad distinction which exists between the "power" of water in a mill-pond and the "work" it does in tumbling over a water-wheel. If the water remained a thousand years in the pond, it would do no work, but would be like the apple suspended from the tree. During all that long period, however, it would retain a capacity for work, just as

the apple retains a capacity for falling; and this capacity would vary in the proportion of the quantity of water the pond contained. In summer it would be less, and in winter after the rains it would be more. Now, the world is a storehouse of such elements of power as we see in the mill-pond. When we begin to trace the causes of these different sources of power, we find they are continually shifting back and back and back, until at last we are obliged to look for their origin among the first conditions of force, about which we know nothing at all. In the case of the mill-pond, we can readily discern the more immediate causes of the power which is stored in it. Where the water that fills it comes from we cannot exactly say—perhaps it came from the Pacific, and perhaps from the Atlantic Ocean—but as we know it came down in the form of rain, the only reasonable conclusion we can arrive at is that it has been carried by the winds in the form of clouds, from some hot latitude largely supplied with water, where it rose first of all in the condition of vapour. It is very easy, therefore, to come to a satisfactory conclusion upon the immediate origin of the "power" in the mill-pond, and to fix upon the sun, whose heat first evaporated the water, as its source and origin. When we trace the supply of "power" to the heat of the sun, however, our difficulties are only beginning; but as this is out of the region of terrestrial physics, we cannot pursue the inquiry further; partly because at this stage it is made up, to a great extent, of theories that have never been proved and are perhaps incapable of proof, and partly because it is really beyond the scope of the present paper. It is enough for our purpose if the reader is able to understand the difference between the conditions of power as it exists in the mill-pond and the "work" which it does in falling over the water-wheel. There is another point which has been sufficiently indicated to enable some explanation to be given before proceeding. As we find that some cause has been at work to produce the capability of doing work in the mill-pond, so we may be certain that throughout the entire storehouse of nature, wherever we discover a capacity for "work," so certainly we may predict that some sort of force has been the agent which produced it. When we come to consider where these conditions of power are illustrated, we discover them at every step of our daily life. It so happens that in the case of the mill-pond we have to deal with a fluid which is so readily subservient to the laws of gravitation, that it willingly follows every curve and bend of the mill-race, and splashes merrily over the mill-wheel, as if rejoicing in its usefulness. If, however, we take the solid instead of the fluid condition of matter, we find the very same principles of latent energy, with the simple difference that in the case of the water they are readily available for the uses of men, and in the case of rocks and stones, lying high up upon the mountain tops, they are like lazy but powerful slaves, who cannot be made to work at all. It is quite certain that the stones of a highland "corrie" never came there by the agency of the sun raising their particles to the skies in the torrid regions of the equator, as happened in the case of the drops of water that make up the liquid volume of the mill-pond; but we may be certain, nevertheless, that force of some sort was at work when they were first raised to their present position, and it is equally certain that if they could be made to tumble peaceably over a mill-wheel without breaking it to pieces they would do an amount of work which would be measured by their weight multiplied by the height from which they descended. Pursuing this train of thought a little further, the reader will now be able to see that in a large town even the stone and lime of which the houses are built are in fact great storehouses of "power," and although the value of the buildings depends upon all this "power" remaining in a state of complete repose, still just as the water in the mill-pond and the stones in the Highland "corrie" are capable of doing work if the one is allowed to rush through the sluices and the other to tumble down the hillside, so our bricks and chimneys, if they were able to get to "work" by tumbling about our ears, would be powerful to do a great deal of damage before they reached the level of the ground beneath. Moreover, just as we discover the agency of the sun in the mill-pond and of some primordial forces in the high-lying rocks of our mountains, and, indeed, of the elevated masses of the mountains themselves, so among our bricks and chimneys can we discover an original supply of energy in the patient labours of the hod-man who climbed with his back-load of materials to the different courses of the house which he helped to build.

As long as the word *power* was applied to wind and water, the good people who made use of these natural forces to grind their corn troubled their heads very little about its scientific meaning. It was nothing to them that the word "*power*" ought really to be applied to their supply of water before it was allowed to fall over the dam; or that the measure of the water-power

was the weight of the water multiplied by the height at which it lay in the pond above the water-wheel. It was nothing to them that the proper term to apply to the water as soon as the sluices were lifted, and it escaped roaring and splashing over the water-wheel, was "work," and that the efficiency of its performance depended upon a variety of conditions, superadded to the great factor of "power" which it retained in the quiet repose of the mill-pond or lake. It was enough for them that the water ground their corn. So things went on for centuries, and no one troubled themselves to use the word "*power*" in any other sense than their forefathers had used it before them. A new state of things, however, arose when the forces of nature were beginning to be found insufficient for the wants of the population, and when James Watt was inventing engines that could be put upon wagons, and conveyed from one part of the country to the other, and erected when they were needed in such a manner as to supply more power than the mill-pond or the river. Then, people, before they parted with their money, wanted to know what they were getting in exchange for it, and if one manufacturer paid £1,500 for an engine, he wished, naturally enough, to be quite sure that he was getting £500 more value in "power" than his neighbour who only paid £1,000; and so some standard became necessary by which the value of his engines could be estimated, and James Watt hit upon the expression "horse-power," and applied it to the sale of his engines. It was here that confusion arose from the scientific misapplication of the word "power," and this I will try to explain by showing what mistakes were made in applying this word to such a purpose as a standard for the sale of steam-engines. It becomes apparent, in the light of the explanations we have already made, that a steam-engine without the boiler has no power whatever if it happens to be erected at the level of the sea.

To speak, then, of the "power" of an engine, independently of the pressure of steam in the boiler, was clearly a misapplication of the scientific use of the word; and this was what was done when the term "horse-power" was applied to the steam-engine, without any notice being taken of the pressure of steam which was necessary to drive it. What was wanted at the time was simply some standard by which engines could be bought and sold, so as to enable the buyer to know that he was getting a fair value for his money, as compared with his neighbours who were buying engines as well as himself. Accordingly, we find the rules for the nominal horse-power of an engine to be based upon the area of the cylinder and the length of the stroke of the engine, together with the velocity at which the piston of the engine travelled. If the reader considers these conditions for a moment, he will see, in the first place, that, although the rules which were framed upon them are called rules for nominal horse-power, there is no idea of "power," in the scientific sense, conveyed by the terms at all; and that, in the next place, they are equally defective as rules for "work" or efficiency, as the pressure of the steam, upon which the amount or work altogether depends, is entirely excluded. These rules, then, were really framed on a false scientific basis, and gave rise to a misapplication of the word "power," which has been adhered to ever since.

For the practical purposes of a standard in the buying and selling of engines, it was well, perhaps, that Watt did not include the factor of steam pressure in calculating the nominal horse-power of his engines, for the simple reason that the standard of one period would have been quite false for another. There were no difficulties in the early manufacture of the steam-engine which proved to be more obstinate, or which were more slowly overcome, than those which beset the engineer in providing a strong and suitable vessel for raising and retaining the pressure of steam. As time went on, however, improvement followed upon improvement, until a pressure of steam and an economy of the fuel required for raising it was reached that rendered all calculations of the nominal capacity for work of the early steam-engines quite unsuitable for the present day. So much is this the case, that the buyer of a modern marine engine is not likely to be satisfied with his bargain unless he gets six times the amount of work from his purchase that would have been considered a fair allowance for an engine of the same dimensions in the days of Watt, when the rules for nominal horse-power, unscientific though they were, still indicated approximately the actual work which the engines were capable of doing.

It is now time for us to inquire in what way the term "power" is applicable to a steam-engine; and in this we shall be greatly assisted by returning to our former illustration of the mill-pond. The reader will naturally wonder what there is in connection with a steam-engine that is like a mill pond: but when we go back, and call to mind

that the mill-pond was only a storehouse of energy, which we found had been laid up by the heat of the sun evaporating the drops of water that composed it, there will be no great difficulty in finding the analogy in the heat of the boiler-furnace which raises the steam. In the case of the mill-pond, the water which constitutes its power rose to the skies in the form of vapour, which saturated the hot air and ascended along with it. Here we find the heat of the sun expanding the elastic fluid of the atmosphere, according to laws that are quite invariable, and—except that these laws come under somewhat altered conditions in the evaporation and is sufficient to point out that the force of gravity, as represented by the height to which the water has been raised, is the work which the heat of the sun has done, and which has been transformed into the power of the mill-pond; while the expansive force inherent in an elastic fluid at high temperature, and which is a storehouse of power in the boiler, has been the result of burning fuel in the furnace of the steam boiler.

The work done by the mill-pond and the steam-engine is therefore quite a separate affair from the "*power*" both of the water and the steam, which, but for evaporation in the one case, and loss of heat by

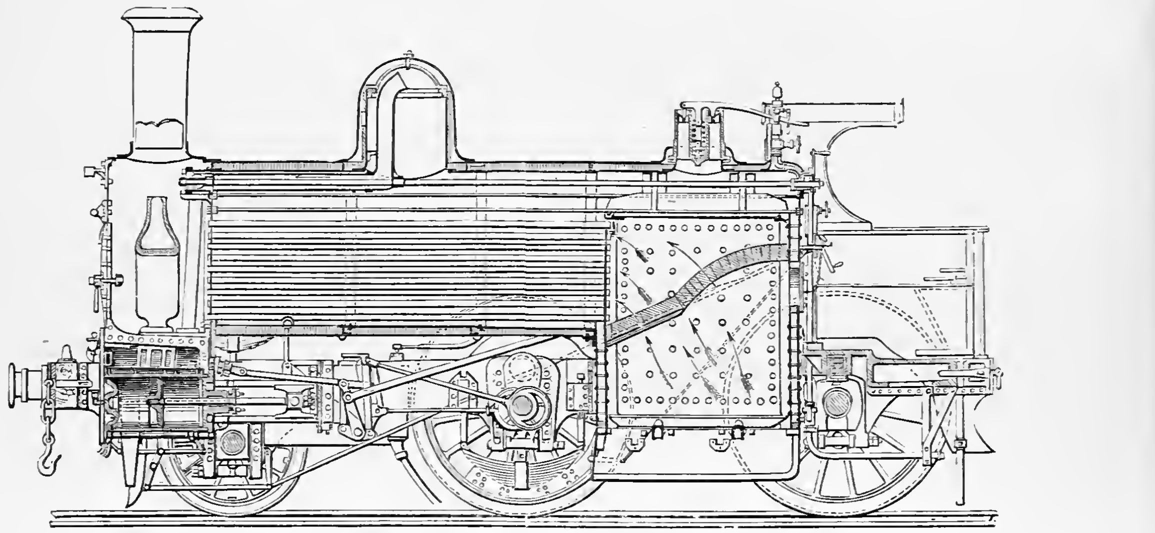

Fig. 1.—Section of a Locomotive Steam-Engine.

expansion of steam—we see exactly the same process at work with the heat of the boiler-furnace. For every degree of temperature which is added to the heat of the steam, it expands to an extent that has been clearly determined by experiment; or if it is confined in such a way that it cannot escape, then the pressure increases as a sort of *quid pro quo* instead of the expansion. Now we have already stated that wherever in the great storehouse of Nature we discover a capacity for work, so certainly we may predict that some sort of force has been the agent which has produced it. In the case of the mill-pond, we have seen that it had its origin in the heat of the sun; and now we find that the "power" stored up in the boiler of the steam-engine depends upon the heat of the furnace. At some other time we hope to speak of those transmutations of force which render power available for doing useful "work;" but in the meantime it

conduction in the other, might be stored up for years without doing work at all, like the lazy stones on the sides of the mountains. The moment the sluices are raised or the steam valve is turned, the "*power*" both of the water and the steam immediately disappears; and it is the aim of the engineer to take the fullest advantage of the *work* into which the power is capable of being converted.

Upon referring to the engraving (Fig. 1), which represents a section of a locomotive steam-engine, the store of power is seen in the fire-box, where the arrows point in the direction taken by the flames and heat of the fuel on their way through the boiler-tubes to the chimney. The heat in its passage is communicated to the water, which is then converted into steam, and so confined in the boiler that it becomes a reservoir of "power." When it is allowed to pass into the cylinders, it drives the pistons backwards and forwards, giving

a rotary movement to the driving-wheels, which thus become the ultimate medium of doing the work of locomotion. The measure of the power is to be discovered in the amount of heat in the steam, and the measure of the work performed will be found in the mean pressure, which is the result of the heat multiplied by the area of the pistons, and by the distance they travel in a given time. If the work is measured by the heat only, it will increase with the difference of the temperature at which the steam enters the cylinders and that at which it leaves them.

Turning now to the storehouse of *power* which we discover among the forces of nature, we must ask the reader to look upon the earth in its relation to the heat of the sun. If we pull a spiral spring and hold it in that extended position, it will have a constant tendency to return to its original length; and the moment we release it, if we have not stretched it too far, it will rebound with an amount of force that is the equivalent of that which was necessary to stretch it. In the same way, if we raise a weight from the ground the force necessary for this purpose will always remain upon sentry, as it were, ready, like the spiral spring, at a moment's notice to take advantage of the first opportunity to return to its original level. Now we find that those regions of the earth which are termed temperate, either from their distance from the equator, or from their great height above the level of the sea, are the storehouses of power which we get as an equivalent for the work done by the sun. All day long and all the year round the sun is evaporating water which saturates the atmosphere and rises along with its expanded volume to the level of the clouds. Just as we have power stored up in the extended spring or the elevated weight, so we find it among the water of the clouds, which may be looked upon as vast attenuated mill-ponds. When these are conveyed to more temperate climates, or come in contact with the cold surfaces of elevated regions, they are condensed, and come down in the form of rain, when they are gathered together in lakes and hollows. But while we thus find the sun to be the origin of these vast natural supplies of "power," we discover also that the same agency is, in a great measure, essential to their capacity for doing work, which is the great characteristic of "power." Among the particles of matter which are the vehicles by which the work of the sun's heat is converted into power, and which are again capable of being the medium by which this *power* is re-converted into work, we find that heat is necessary to the fulfilment of these functions. If the clouds raised by the sun's heat are carried into regions of continuous frost, they are bound in chains that preclude them from being subservient to the uses of men, and they lie in snowdrifts and glaciers, like the afore-mentioned idle rocks. And so it follows that it is not among the burning plains of the tropics, where the heat of the sun is greatest, nor yet in the regions of continual frost, that we discover the great storehouses of *power*, but among the more temperate parts of the earth, where we seem to find an analogy for the forces of nature in the greater activity and higher development of men. In the winter of the Greenlander there are no falls of rain to fill the mill-pond that turns the wheel that grinds the corn of the fortunate inhabitants of more temperate regions. The wind still howls around his hut, for it cannot be bound in the chains of winter; but if the sun should cease to shine, even the winds would be still, and the earth would be given over to the silence, and darkness, and practically *powerless* repose of an Arctic midnight.

Although we have confined ourselves to a consideration of *power* as exhibited in water and steam, a study of the forces which gave rise to the capacity for work in these cases opens up one of the widest fields of physical inquiry, and removes us from the regions of terrestrial agencies to a study of the storehouse of *power* which we discover in the sun. Meantime, our object has been attained if we have explained the scientific meaning of the word "power," which, if it had never been misapplied, might have served all the purposes of a longer and less English expression—that of Potential Energy, which is its scientific synonym.

HISTORY OUT OF REFUSE HEAPS.

By Robert Brown, M.A., Ph.D., F.L.S., Author of "The Races of Mankind," etc.

THE student who has eyes and has learned to use them, cannot walk along our own shores, or, indeed, along the shores of almost any part of the world, without observing the ceaseless warfare which is being waged between the sea and the land. The waves are breaking against the cliffs—those "eternal walls," which seem to the ordinary spectator the visible type of unchangeableness—returning again and again to the charge, until in time they undermine the great bulwark, and sweep it into the bosom of the ocean. Again they renew the attack, never idle, always busy, until, yard by yard and rood by rood, the sea eating into the countries bordering it, the coast-line is altered, and old historical landmarks live only in the books of chroniclers. If this went on for ever, by and by the sea would roll over the whole world. But there is a counterbalancing influence at work. The result of this influence we see in the form of the long line of shells and other marine refuse which encircles many portions of our coast. At first glance we might suppose this to be caused by the winter storms dashing the spray, and the *débris* along the beach with it, high above the ordinary tidal mark. But a slight examination shows that this theory is an erroneous one. In those old sea-beaches lying some way inland from the present ones, we see that the material of which they are composed is much the same as that on the shore over which the sea rolls twice a day. Shells are their chief constituents. The shells, moreover, are to a great extent unbroken, and in many cases evidently in the position in which, when they contained animals, they had lived in the sand and mud in which they are still imbedded. It is at all events clear that they have not been disturbed by the hand of man, and that the beaches on which they lie were elevated by a slow rise of the land. This rise is, we know, going on in many parts of the world to the present day, while in others there is an equally clear and gradual sinking of the shores. But if we prolong our investigations, we shall come upon other shell-mounds which, though at first sight seemingly the same, are in reality very different. For instance, on certain portions of the coasts of the Danish Isles, we come upon enormous accumulations of dead shells, sometimes five to ten feet in height, several hundred feet in length, and in many instances one hundred to two hundred in breadth. We see that these mounds occur only at intervals. That in itself is not important, for the whole coast, even when of the same character, need not necessarily have afforded places for marine shells to live. We also see that these mounds are elevated, like the old sea-beaches, at considerable heights above the sea-level. A closer examination of the Danish shell-mounds, however, reveals many differences. For example, while, on the neighbouring shores and in the raised sea-beaches with which we have already made acquaintance, the shells are of all ages, in the mounds under consideration they are chiefly adults, the young being notably absent. Again, these mounds are not composed of the shells of molluscs all living in the some locality, and therefore could not have been found naturally in each other's company. This at once strikes a fatal blow at the theory that they belong to a raised sea-beach. Nor do we find the heaviest shells lowest down, as is always more or less the case when water has had anything to do with the sorting of materials. On the contrary, we find big and little, light and heavy, mixed up in such a manner that it is evident that since the component members of the shell-mounds came—no matter how—into the position they now occupy, the sea has had nothing to do with them. On examining these mounds more closely, it is found that they contain the bones of animals, and among these the bones of some species now extinct, but which it is known have existed in the North of Europe within historical periods. A still more exhaustive search discloses a few of the most primitive tools. These consist of rudely-formed weapons of flint, with splinters which have evidently been detached in the manufacture by chipping of their primitive knives and arrow-points (Figs. 1, 2, 4, and 5). Along with the flint weapons—which show without any possible doubt the presence of men at the time these mounds were formed—we find some rude pottery — the work evidently of the most untutored artists; an implement which is believed to have been a spindle; charcoal, and cinders. The bones are those of wild animals, such as might be used for food. No domestic animal, except the dog, has left any trace in these shell-mounds; and in vain do we search for the presence of iron or of

that bronze which, according to archæologists was characteristic of a still earlier and less civilised

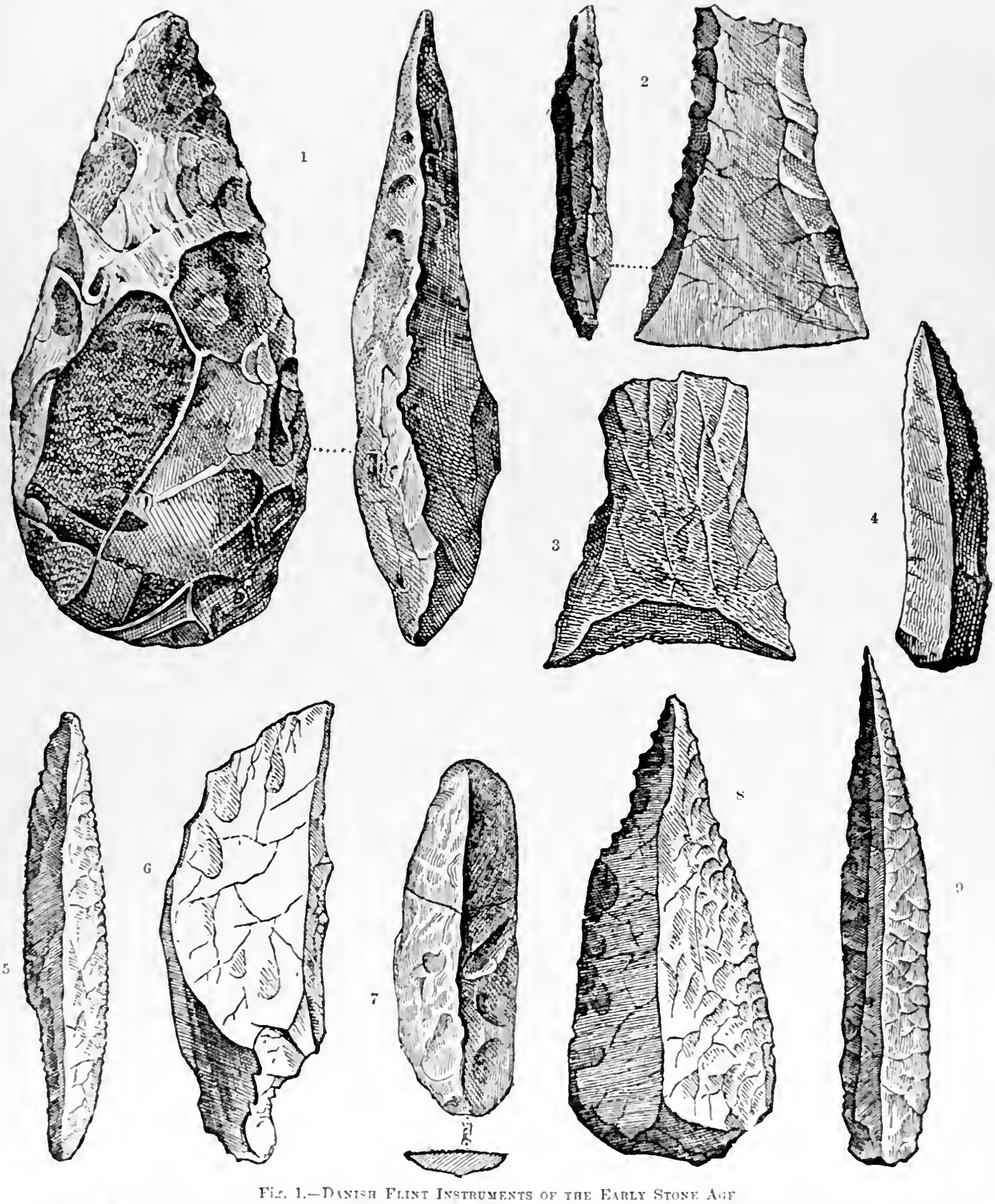

Fig. 1.—Danish Flint Instruments of the Early Stone Age

(1) Spear-head, front and profile; (2) Hatchet, front and profile; (3) Scraper, for dressing skins, &c.; (4) Knife; (5–7) "Worked Flints," probably Spear-heads spoilt in the making; (8, 9) Spear-heads(?)

people than those who constructed their weapons and domestic utensils of iron. It is thus clear that the Danish shell mounds were the work of *man*, and not due to any natural cause; that the men who made them lived at some very remote period, otherwise the bones associated with them would have been those of animals either now found in Denmark, or which have become exterminated at

a later period than we know the bones of those found in these mounds have; and lastly, that the men whose work these heaps of shells are were of a low type of civilisation, and, at all events, very different from any Danes with whom the very earliest histories have made us acquainted. These are the "conclusions" from the "premises" before us—and very justifiable ones, too, according to all scientific methods of reasoning.

The next step in advance is to find out, if we can, who were the people who made these shell-mounds, and for what purpose or in what operations parts of the coast where the sea wears away the shores, they have long ago disappeared, a great portion of Denmark being elevated but little above the sea-level. They are also found in close vicinity to the water, the exceptions to this rule being in cases where it can be proved that their *locale* has been altered either by slow elevation, by silting up the sea with mud, or by the formation of peat, which has made inroads on the sea. In no case, however, where they have been undisturbed are they found within reach of the waves even during the roughest of weather—another proof that those who formed

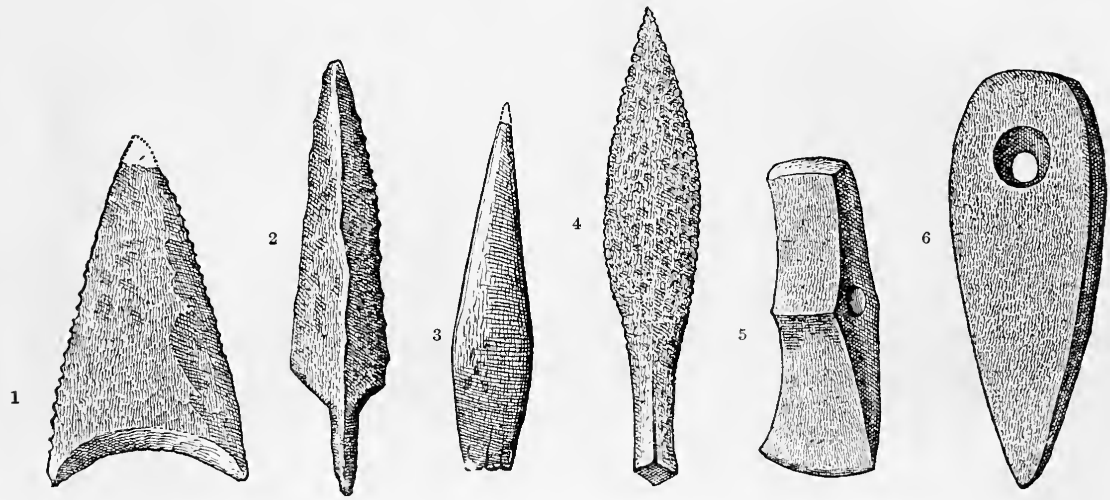

Fig. 2.—Danish Flint and Horn Implements of a later Date and of more finished Manufacture than those represented in Fig. 1.

(1, 2) Common Types of Arrow-heads; (3) Arrow-head of Reindeer Horn; (4) Spear-head, not polished, but more finished than the rudely chipped ones; (5, 6) Axe-hammers, drilled for Handles.

they were made. Now, should we confine our observations to those on the Danish coast, we might arrive at sufficiently accurate conclusions, but still, as the data are limited, it is as well to inquire whether such mounds are confined to the shores of the Scandinavian Islands, or are more widely spread. Following up this investigation, we find that not only have they been observed in the island of Sæland, that on which Copenhagen is built, and especially along the shores of the shallow inlet known as the Isefjord, but they are also found on the coasts of the isles of Fünen (Fyen), Moën, and Samsoë, in Jutland (Jylland), along the Liimfjord, the Mariagerfjord, the Randersfjord, the Kolingsund, and the Horsensfjord, and, most probably, also along the southern part of Denmark, though still waters seem to have been loved of the shell-mound builders. It is, however, possible that the reason why we find them in such localities is because on them must have lived in their close vicinity, otherwise they would not have been so careful to put out of reach of destruction heaps of materials so seemingly valueless, though artificial. If we may have formed any theory which would make these shell-mounds in any way specially connected with the North, or its early civilisation, it is speedily dissipated by discovering that not only are they found in Denmark, but also in Sweden, and not only in Scandinavia, but also in the extreme South of Europe—for near Mentone, in the Gulf of Genoa, are heaps almost identical—and likewise along the shores of Great Britain. The latter are, however, to all appearance, judging from the remains, the work of a people of a later date, though the uses to which they have been put are identical. The Scottish shell-heaps bring us up nearer to our own times, and lead us to ask whether or not people in a low stage of civilisation—in other words, those

who are familiarly called savages—have not in their belongings something similar to those old shell-heaps of the shores of Europe? We do not require to seek far afield; for wherever we find a coast-tribe of savages, they live to some extent on shell-fish, and whenever they have abundance of shell-fish to live upon they have, not far from the doors of their huts or wigwams, formed mounds which are identical, except, of course, in the kind of shells and other in brief, the refuse heaps of the lazy, mollusc-loving Indians. They eat the clam, the cockle, or the oyster, and toss the shells outside their doors. They devour a wild duck, a grouse, a salmon, a deer, or a beaver, and deposit its well-picked bones in the same general receptacle. They split the elk's leg-bones to obtain the marrow, and into the refuse heap go the *disjecta membra* of that marrowless femur and tibia. A hunting-spear is

Fig. 3.—KITCHEN-MIDDENERS AND THEIR DWELLINGS.

remains composing them, with those which we have already briefly described. Along the whole shores of North America, on those of Brazil and Ecuador, and even in Australia, these shell-heaps are found. From Newfoundland to Florida there are immense mounds of them at intervals along the coast, and the present writer has investigated them on the shores of Vancouver Island and British Columbia, where, as at Beacon Hill, in the vicinity of Victoria, they contain flint weapons no longer used among the coast natives. In these regions we do not, however, require to speculate regarding their mode of formation, or presage it from an inductive study of the contents, for they are still being formed. They are, broken, and in due time to the refuse heap go the fragments. In a word, when the hunter's lodge is swept—and even Indian lodges are sometimes swept, though not always recently—all the fragments of his meals, his sports, and his industries, such as they are, are deposited among the shells close by. But if there is on the muddy flat within a stone's throw of their door a bed of "clams," or other mollusc, naturally it forms the staple of the Indian family meals, and its bulky shell accordingly composes the greater part of the ever-increasing shell-mound by the single hut, or the hamlet where the icthyophagous fishers live. Indeed, it comes within the writer's knowledge that

sometimes these shell-mounds, and other refuse heaps, have become so uncomfortably large that the Indians have had to remove the village. In a more refined state of society, the refuse would first have been removed, but lower down in the scale of civilisation a contrary state of matters prevails. But we need not go all the way to Vancouver Island to see such a shell-mound in process of accumulation. At any fishing-village along the coasts of England or Scotland, an almost exactly similar one is being formed in front of the village doors. Ask the fisher-folk of Yorkshire, Northumberland, or Lowland Scotland what such a mound of oyster, cockle, and mussel shells, and other domestic refuse, is called, and they will tell you a "midden"—an expressive old word of Danish origin, which has unhappily been allowed to drop into oblivion, or to be consigned to the limbo of too homely or slightly vulgar expressions. Need we, therefore, doubt what are the Danish and other shell-mounds which early in this paper we made the acquaintance of? They were the refuse-heaps of the very ancient coast tribes—we shall not say savages—who dwelt along the coast of Denmark before books were written, or runes engraved by mortals loving immortality. Indeed, so evident is this that the Danes have applied to them the name of *Kjoekkenmoeddinger*,* or "kitchen middens," from *Kjoekken*, "kitchen," and *Moedding*, "refuse or rubbish heap." Under this name, accordingly, they are now known to science, and "kitchen middens" we shall accordingly designate them so long as we ask the reader's attention to the curious tale which they reveal.

What, then, do we learn from them? Lordly monuments some nations have left to record their prowess or their greatness. The frail huts even of the rude rearers of the kitchen middens have long ago passed away (Fig. 3). Others leave their records on their tombs—if not in inscriptions, at least in their arms and utensils, which are to be used in the happy hunting-grounds; while the tell-tale skull enables us to know what manner of intelligence this unlettered forefather of ours had. But no trace of carven stone, not a bone of his, not an arm save the rude flint spear-head, not a domestic utensil save the broken potsherds which were tossed aside as worthless, have descended to us who have come into the heritage of the Kitchen-middeners. A people have passed away, and left their history to be deciphered from their dunghills!

Yet that history is not an uninteresting one, and the materials we have to deal with have, in careful hands,† proved much less deceptive than many a ponderous volume of lying chronicles. It is evident that the life of the people who accumulated the kitchen middens was a merely animal one. If they had a higher life than that which was devoted to supplying their slender wants, we shall never know it. There is no likelihood that they knew anything of the art of agriculture, or that, with the exception of the wild berries of the woods and moors, they had any vegetable food. As sea-weeds are scarce in the Baltic, it is not probable that, like the Eskimo, they could vary their flesh and fish diet with this homely fare. In some of the mounds there are remains of charcoal and ashes, and in the contiguous soil a dark carbonaceous-looking matter which is probably the ashes of the eel-grass, or *bændeltang* (*Zostera*), — about the only marine plant which at this day borders the coasts of the Danish islands. Less than two centuries ago this eel-grass was employed for making a coarse salt by macerating the leaves of the plant, and it is not unlikely that those very old Danes also used this means for obtaining some material to flavour their tasteless diet, the Baltic being very brackish, and not a very promising source for salt. The shells which make up the greater part of the kitchen middens are the common oyster, cockle, mussel, and periwinkle (*Littorina*), their relative frequency being in the order in which they have been mentioned. Here we see evidences of some great physical and biological changes. The oyster, which seemed to have formed the bulk of the meals of those simple Epicureans, has now almost entirely disappeared from all the regions east of the Kattegat, and more southerly than the shore-line of Sæland. In the Kattegat even it now only exists in isolated individuals, and nowhere in such abundance as would supply food for any great number of people, even with that toil in searching for them which hungry and most likely very lazy Kitchen-middeners would never devote to them. At one point only—namely, between the island of Læssö and the northern extremity of Jutland—has an oyster-bed ever been worked within the memory of man. At one time a few were got from a locality at the entrance to the Isefjord; but the great increase of

* This spelling is now somewhat archaic, and has given place to *kökkenmöddinger*.

† In addition to much information obtained directly in Denmark and elsewhere, and from the original investigators and their collections, it is almost needless to say that the data here given owe nearly everything of value to the researches of Steenstrup, Worsae, Forchhammer, and Lubbock, and to the memoir of Morlot in the *Bulletin de la Société Vaudoise des Sciences Naturelles*, t. vi.

the common startish, which preys on them, led to their extermination. Yet in ancient times the whole of the Isefjord was one great oyster-bed, and in that inlet there can still be seen *in situ* dead the very old Danes the whelk (*Buccinum nassa* and *B. undatum*), both of which, though inferior food, are still eaten, and *Venus palustra*, also an edible shell-fish, though, like the other two, not much in

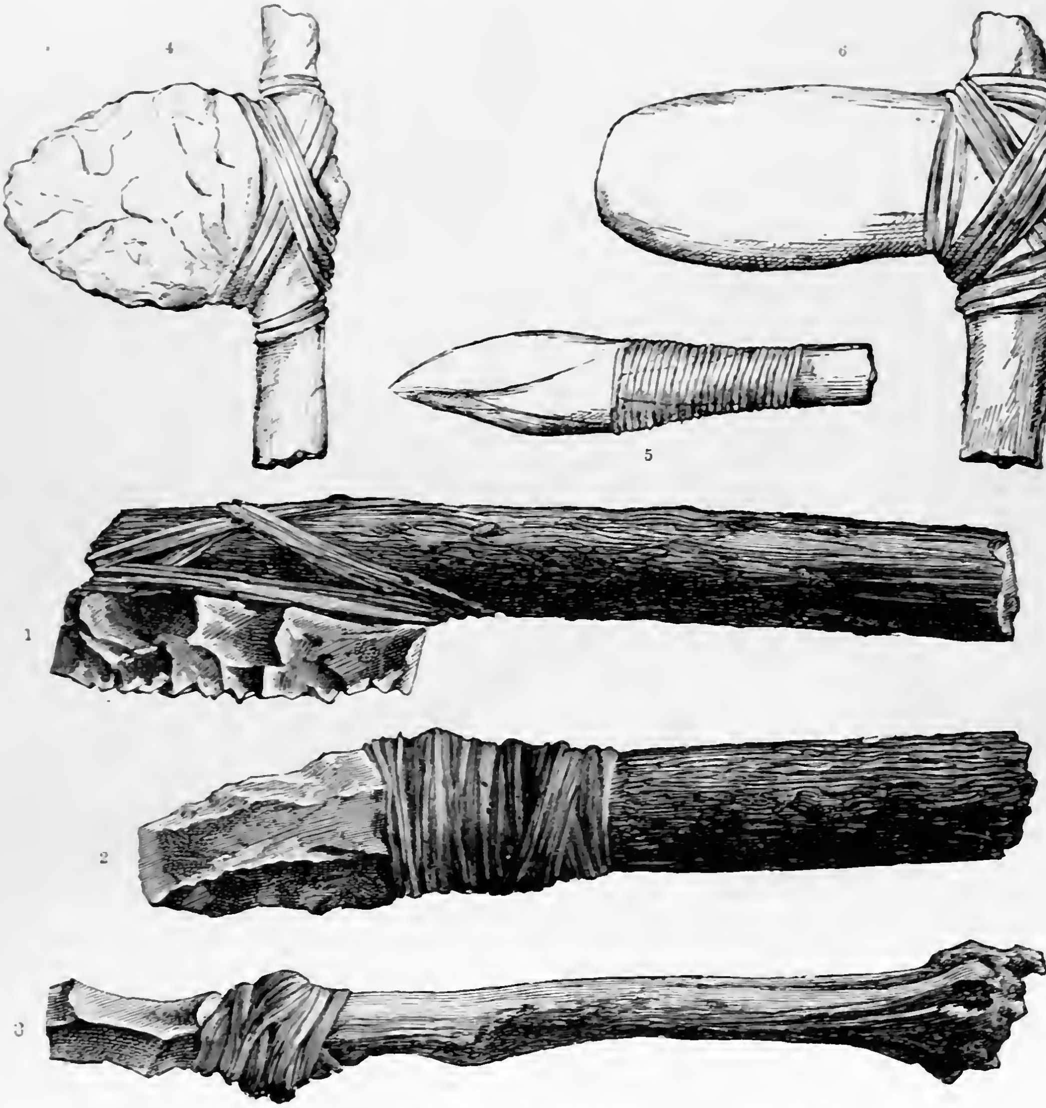

Fig. 4.—Showing the probable Way in which the Early Flint Weapons were used.
(1) Saw; (2) Chisel; (3) Knife; (4) Axe of chipped Flint; (5) Spear of ground Stone; (6) Axe of polished Stone.

shells, showing that the animals originally in them must have been destroyed by some physical change in their surroundings—probably by a decrease in the saltness of the Baltic. We also find the periwinkles and cockles of the kitchen middens larger than those at present found in the Baltic. In addition to the oyster, periwinkle, and cockle, we find in these monuments of the gastronomic tastes of request, and rather rare in the Danish waters. Crabs are uncommon in the sea adjacent to the sites of the old fish-eating savages, and accordingly there are few traces of any kind of crustacea. Cod (or, perhaps, dorse), flounder (or dab), and eel bones are, however, abundant, but those of the herring are the most common of all. These remains not only give us an inkling as to the dietary of these extinct

savages, but also enable us to learn that they must have had canoes, otherwise they could not have procured oysters, which are found in deep water; while the herring and cod rarely come in so close to the shore as to be able to be captured by a people without some kind of craft, either rafts or rude "dug-outs," such as are used by the least mechanical of modern barbarians. Eels—a favourite dietary of the Kitchen-middeners—seem, curiously enough, to have been in these remote times common in the same localities as they are in our day. For example, the neighbourhood of the town of Aalborg is, as the name of the place signifies, famous for its eels, and it is just in this vicinity that the kitchen middens yield the greatest number of their bones. As might be expected from a shore-living people, aquatic and palustrine birds were those which they chiefly used as food; among these, the wild swan, wild geese, and various species of ducks. The capercailzies' (*Tetrao Urogallus*) bones are also found; and what is still more interesting, in the kitchen middens we come upon remains of the all but wingless bird, the great auk (*Alca impennis*), which, owing to the facility with which it was killed, is believed to have become extinct about forty years ago. At all events, since that date none have been seen in its old haunts, and a specimen would nowadays be worth rather more than the conventional "king's ransom." At one time it was so exceedingly abundant in Iceland, Newfoundland, Orkney, and other northern localities, that ships' crews were in the habit of provisioning their vessels with it, and no doubt the old Kitchen-middeners found its squat, fat carcase an easily acquired addition to their by no means monotonous diet. The domestic fowl is absent, nor have the *kjoekkenmoeddinger* yet yielded any remains of the two swallows which now frequent Denmark, nor of the stork so common on roofs and on church towers in that country, and the domestic sparrow of cosmopolitan habits. The most numerous quadrupeds which—judging from the relative abundance of their remains in the shell-heaps—supplied the "table" of the Kitchen-middeners seem to have been the red deer (*Cervus elaphus*), the roe (*Cervus capreolus*), and the wild boar (*Sus scrofa*)—the last now extinct in Denmark.

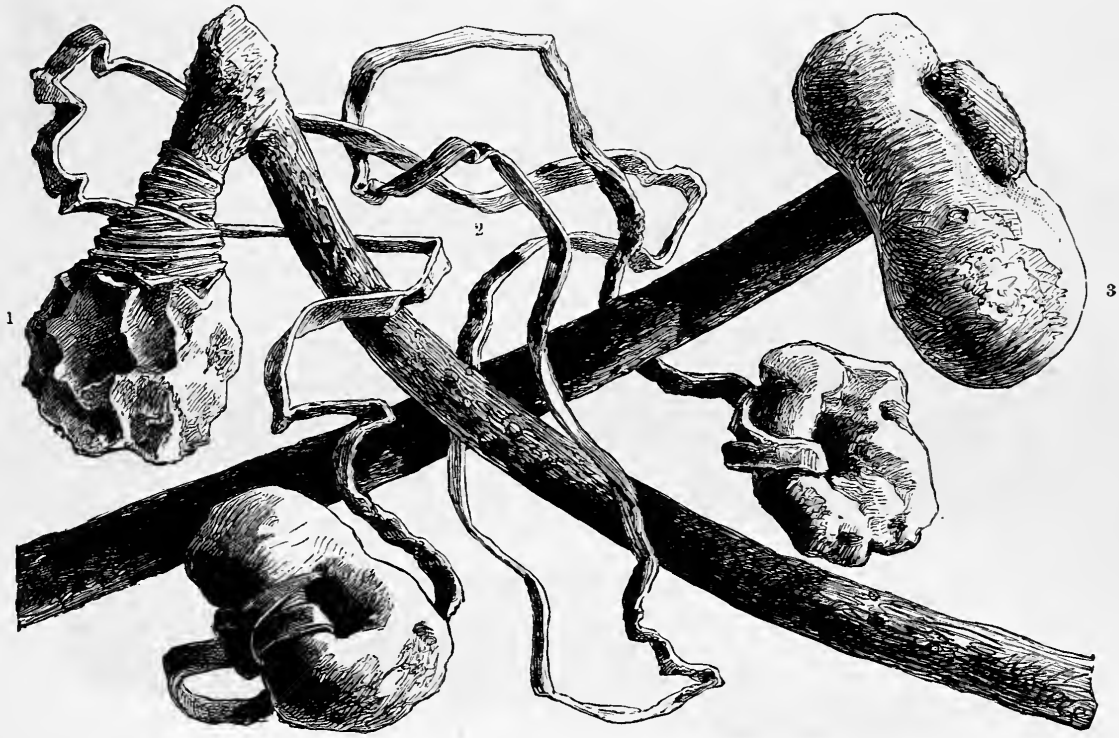

Fig. 5—Showing the probable Way in which the Early Flint Weapons were used.
(1) Adze of chipped Flint; (2) Implement allied to the Bolas of South America; (3) Hammer.

The urus (*Bos primigenius*), the Beaver (*Castor fiber*), and the Grey Seal (*Halichœrus gryphus*), are also so often met with that they must have supplied

much of the food of these primitive people. The beaver has not been known as an inhabitant of Denmark for more than 900 years. The seal, though rare, is still occasionally seen in the Kattegat; while the urus or wild ox has been long ago extinct. It was seen by Cæsar; and one of the last records we have of its existence in Europe is in a manuscript of the tenth century, in which it figures among the viands that appeared on the tables of the monks of St. Gall, in Switzerland. The elk and the reindeer have not yet been found in the kitchen middens, though it is highly probable that they were contemporaries of the people who made these mounds. Among other quadrupeds, the bones of which have been disinterred from these refuse heaps, are those of the wolf, the fox, the lynx, the wild cat, the sable, and the otter; but none of them are so common as those already noticed. The bones of the hedgehog and the water-rat are also accidentally found, as well as bones gnawed by these latter animals. No trace of the hare, a common animal in Denmark, has been found. This curious omission may be accounted for by the fact that, from very early times, the Northern people have regarded this animal with superstitious feelings, and accordingly the Kitchen-middener might have objected to eat it, except when compelled by the direst necessity. A small-sized dog is the only domestic animal whose bones have been found. Its habits seem to have been very much the same as its modern representative's. Give a domestic dog the carcases of birds to devour, and it will be found that it will swallow all the bones except the long ones. Accordingly, it is interesting to find in the kitchen middens numerous gnawed long bones, off which all the cartilaginous parts have been stripped, and on which the marks of the teeth of these old carnivora are distinctly seen. It is also not unlikely that the Kitchen-middeners ate the dog, as is still done by many modern savages, and, indeed, by some people who would be shocked to have such a name applied to them, for on its bones are often found the marks of knives. The bones of young nestling birds, of which at present there is a great consumption in Jutland, are absent from the kitchen middens. We must not, however, conclude from this negative evidence that the primitive people were absent from the Danish shores from May to August, for it is more than likely that the dogs which rejected the long bones of birds as inconvenient to swallow, devoured the slender and all but cartilaginous skeletons of the young ones, just as some people devour quails whole. Indeed, we know that these men must have resided on the shores of old Denmark during the whole year, for in their refuse-heaps we find the horns of the deer or roebuck, as well as the embryonic skeletons of these species, and of the wild hog. The presence of the bones of the Wild Swan (*Anas cygnus*) show clearly that the Kitchen-middeners must have been on the coast during the winter, for it is only during the winter that this bird makes its appearance in Denmark. On the approach of spring, it betakes itself to still more northern regions. "It is then especially," writes M. Morlot, "that is heard its harmonious song, partaking of the sound of distant bells, and of the Æolian harp, whence, doubtless, the myth of its death-chant." It is, therefore, in the highest degree probable, though we have no distinct evidence of the fact, that a people who frequented the bleak shores of the Baltic during the winter, would also live on them during the pleasant Northern summer.

What the Kitchen-middeners did with their dead we know not. Perhaps they burned them. At all events—unless some round little Lapp-like skulls found in the peat are theirs—not actual traces of the men whose "middens" we have been investigating have been found. Here and there in some of them we come upon a skeleton, but these skeletons are simply those of some shipwrecked seaman, who has been buried in the dunghill of a race who have, like him, left no record behind them. The people who came after the Kitchen-middeners, judging from the imposing tombs which they have built, seem to have been great respecters of the dead; and, no doubt, so were their predecessors, but all is conjecture. There are, however, no grounds for believing that they were cannibals, for in these remains of the barbarous feasts, those of men never occur. A few rude flint or whinstone weapons (Figs. 1, 4, 5), and some bits of pottery moulded by the hand (and, as is the case with the pottery of some savage people of our day, mixed with sand to prevent it cracking in the fire), are the chief traces of the handiwork of the people about whose dinners we know so much. Here and there we find—on the sea-shore—hearths of stones, on which, it is probable, on some of their fishing excursions, the Kitchen-middeners cooked their rude meals; and mixed with the pottery, it is observed, is some of the sand formed by the action of fire on the granite stones out of which these fireplaces are formed. These angular sand-grains give the pottery a better consistence. Hence the Kitchen-middeners, though a primitive, were not altogether an unobserving people. The flint weapons are mostly very rude, but now and then one of a more elaborate

construction is found, and the marks on the bones split for marrow, and on others, show that they used sharp knives, well ground, for separating the flesh. So that the presence of splinters and roughly-chipped tools in the kitchen middens may only mean that they threw away the badly-made, or spoilt ones, and kept the finer specimens, which would account for their rarity in the refuse-heaps (Fig. 2). There are also found in the kitchen middens numbers of roughly-hewn pebbles, specimens of which are also picked up imbedded in the neighbouring peat-bogs. These, it is believed, were sling-stones, or weapons of some sort, thrown at birds or larger game, or perhaps at each other in their petty tribal wars. Bits of cut deer-horns, awls, chisels, and even combs, neatly fashioned out of bone and horn, have been among the "finds" in the refuse-heaps of this shadowy race. One other fact we may note, and that is that in the fabrication of their instruments and objects of bone, they selected that portion of the skeleton of the animal which is densest and strongest—namely, the inner side of the radius, or chief bone of the fore-leg. This proves, in the absence of other direct testimony, that these primitive Scandinavians were by no means deficient in practical sense and foresight.

Who were these people we know not, and as to whence they came, or in what manner they disappeared, history is equally silent. Nor is it any more likely that we shall ever learn the fate of the Kitchen-middeners, than "what songs the sirens sang, or what name Achilles assumed when he went among women." It is vain to speculate as to the gods they worshipped, or the demons they feared—as to what were their loves and their hates; or, in this earthly here, of what kindlier hereafter they dreamed. It would be equally idle to try to fix an even approximate date for their era. All we can say is, that the Kitchen-middeners must have lived a long time ago. In all likelihood, there have been, since the time this ancient people flourished, some changes in the physical geography of the Baltic; though this need not excite surprise, as it is considered by many probable that the Oxus has changed its course within historical times, and the Run of Kutch is, we know, of very recent date.

We have seen that the size of the shells makes it likely that the sea was, at the time of the formation of the kitchen middens, salter than at present. It is just possible that this may have been owing to the Baltic in early times being in communication with the Arctic Sea, or, through wider channels than the present one, with the German Ocean, though this is a question too intricate to discuss in this place. The presence of the capercailzie in the kitchen middens also proves that the Scottish fir, on the buds of which it feeds, at that time clothed the shores of Denmark; though since the dawn of history, the fir has never been known as a wild tree of the country. In the peat-bogs, we find a layer of it, and over this layer one of oak, and over all is growing the prevailing and characteristic tree of Denmark, the beech, which is so familiar nowadays as the chief ornament of the wooded shores of the Sound. Did a stronger race, armed with weapons of bronze, appear in the country, and, after the manner of stronger races generally, civilise the Kitchen-middeners off the face of the earth? Were they driven to the inhospitable Land of the North Wind, and are now known as the Lapps or Finns? Did some catastrophe—some great inroad of the sea, such as that to which the Danish isles are no strangers—overwhelm the humble dwellings by the side of the dunghills? There are vague evidences, which some think sufficient to prove this. But we know not. All that we are certain of is, that at very early periods—perhaps contemporaneous with the Cave Dwellers of England, France, and Belgium—there lived on the Danish shores a rude race, who left no more pretentious monuments behind them than the refuse of their dinners; and that in the study of these refuse-heaps, modern *savans* have exercised their reasoning powers in writing the history of a vanished race.

WHAT IS IN THE INTERIOR OF THE EARTH?

By William Durham, F.R.S.E.

THERE are many questions in science which, in the present state of our knowledge, cannot be directly and definitely answered. It is of interest, however, and useful for the advancement of knowledge, that we should investigate such problems, and give an outline or sketch, at any rate, of what the answers are likely to be. As the artist draws first in rough outline the subject of his picture, and

gradually fills in the details, shading one part and bringing into prominence another, until the whole is pronounced by competent judges to be "true to nature," so the man of science may map out his theory, so far as his present knowledge goes, and gradually improve upon it until the plan of Nature is made plain to every observer. Of such a kind is the answer to the question we have started with—"What is in the interior of the earth?" We cannot directly solve the riddle, but must, in the meantime, be content with more or less probable conjectures from known facts, trusting to the gradual advance of knowledge to fill in the details of the sketch we make.

Like every other scientific problem involved in obscurity, the one we propose to investigate has been made, by the imagination of man, to minister to his love of the marvellous before passing under the strict *régime* of scientific induction. It was supposed that the centre of the earth was hollowed out and filled with matter having no weight, but endowed with enormous force of expansion. As it seemed necessary to put this empty space to some useful purpose, it was gradually filled with animals and plants suited to a subterranean existence, and, for their benefit, two planets, named Pluto and Proserpine, were supposed to illuminate the dark abyss. Not to cut this region entirely off from the upper sphere, an opening was supposed to exist near the North Pole, and definitely fixed as at 82° latitude, whence the polar light emanated. Even so lately as the time of Alexander von Humboldt, in this century, he and Sir Humphry Davy were publicly asked by a Captain Symms to undertake an expedition down the huge cavern to investigate the state of matters in this *terra incognita*, if we may call it so.

Of the contents or physical condition of the interior of the earth, we have no positive knowledge whatever, but we may infer some things concerning both, with more or less probability, from certain facts observed on the surface or crust, to which alone we have access.

We shall first describe the various phenomena which seem to bear on the subject, and then give the conclusions which men of science have drawn from them, indicating those which appear most probable.

(1) If we examine the temperature of the crust of the earth, so far as we can do so by means of deep mines, well-borings, &c., we find, after leaving the region under the influence of the sun's heat, that *the temperature increases 1° Fahr. for every 50 or 60 feet we descend towards the interior.* Thus, suppose at our starting-point the thermometer indicates a temperature of 40°, at 50 feet lower down it will indicate 41°; at 100 feet, 42°; at 150 feet, 43°; and so on, as far as we can reach in our deepest mines and wells.

As we know that the rocks of which the earth's crust is composed can be melted if we subject them to a high enough temperature, it seems natural to suppose that if the temperature goes on increasing at the same rate beyond the depth we can reach, there will be a point, not very far from the surface, where these rocks will exist in a melted or fluid state. This point has been calculated to be about twenty or thirty miles from the surface. Of course, the melted rocks must, at that depth, sustain an enormous pressure, as they have to bear the weight of the twenty or thirty miles of matter above them.

(2) Over the whole surface of the earth we have evidence of great internal heat, in the shape of volcanoes, earthquakes, and hot springs. Volcanoes, as we know, exist in various parts of the world, and throw out immense quantities of melted rock or lava, hot ashes, and vapours of various kinds. We have evidence, also, that this action is not confined to any particular regions, but has, at one time or another, manifested itself in every part of the world. Earthquakes also, at various places and times, shake and rend the solid ground, while hot springs perpetually bring up water at a high temperature, sometimes projecting it, with great force, high into the air.* All these things undeniably prove the existence of a high temperature and great pressure somewhere in the interior of the earth.

(3) Another fact of a somewhat different order, which we must consider, is the shape of the earth. This, as every one knows, is not that of a perfect sphere or ball exactly, but is flattened slightly at the poles, something like Fig. 1, where N and S represent the two compressed poles, and the dotted line between them the axis round which the earth revolves from west to east. This peculiar shape is significant; it indicates that the earth at one time was a fluid mass to its surface. It can be readily understood that a fluid sphere, whirling round in the direction of the arrows, from W to E, would have a tendency to fly off into space, owing to centrifugal force, like a stone from a sling whirled in a circle for some time; but, being restrained by gravity, the fluid sphere in cooling would take the modified form of bulging at the sides and

* See Science for All, Vol. I., p. 225.

compression at the poles we know the earth to have: a rigid solid sphere could not take this form. We know the tendency to fly off from the

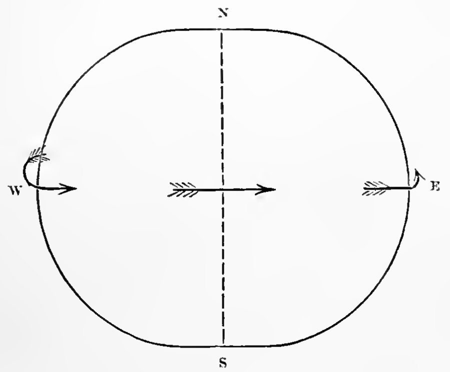

Fig. 1.—Explaining the Form of the Earth, as indicating a fluid Origin.

equator, owing to centrifugal force, modifies the weight of bodies there as compared with the poles. If, therefore, the earth was at one time in a fluid condition, it must have been at a much higher temperature than it is now in order to melt its whole surface.

(4) The density, or relative weight, of the earth, taken as whole, is about five and a half times as great as that of water; that is to say, the whole globe weighs as much as five and a half globes of equal size composed entirely of water. Now, the average density of the rocks, of which the crust of the earth is composed, is only about two and a half times as great as that of water; while if we take the ocean into account, the average density of the whole crust is only a little over one and a half times that of water. Clearly, therefore, the density of the interior of the earth must be very high indeed to bring up the average of the whole to what it is; the materials of which it is composed must, as the saying is, "weigh like lead."

In considering the foregoing facts—viz., the shape of the earth indicating a fluid origin and high temperature; the increase of temperature at a regular rate as we descend into the interior; the existence of volcanoes, earthquakes, and hot springs—we seem irresistibly led to the conclusion that the earth is in the position of a cooling body; that at some far distant period in the past, a thin solid crust formed on the outside of its molten mass; that this crust has gone on increasing as the earth cooled, until now its thickness is between twenty and thirty miles; while below that, primæval fires still hold their sway, and melt the rocks with fervent heat. We seem to see the whole thing before our eyes, just as if we were in a foundry watching the molten iron running into the sand, the light dying out and the dark crust forming on its surface, so thin at first, and gradually getting thicker; although, on disturbing it, the fiery mass shows its unmistakable presence beneath the quiet crust.

This idea, while apparently the most natural, has also been, perhaps, the most generally accepted explanation of the condition of the interior of our planet.

In order that we may have a definite idea of the earth's crust, let us consider a circle like Fig. 2 as representing the whole globe. The thickness of the circumscribing line will nearly represent the crust, while the inclosed space will represent the melted or fluid interior.

The foregoing conclusion, although very generally accepted, was not universally so. Many eminent men, not satisfied with the idea of such an enormous melted nucleus (for reasons to be afterwards noticed), sought to explain volcanoes, earthquakes, internal heat, &c., in other ways. Poisson supposed that, at some former period of its history, the earth passed through some region of space which was at a much higher temperature than itself, and consequently the earth got heated from the outside

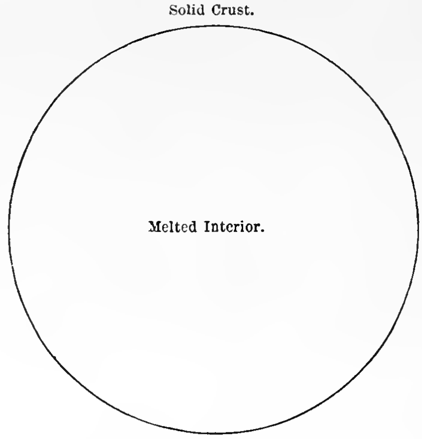

Fig. 2.—Diagrammatic Representation of Earth's Crust and Interior.

inwards to a certain depth, and is now cooling down again. This idea may be passed over as a pure conjecture, for which there is no evidence whatever. Some others, among whom was Sir Humphry Davy, imagined the central heat of the earth to be due to chemical action, which, we know from experience, to be capable of producing intense heat, since all the heat we utilise in our fires and furnaces is due to this action; and it is not improbable that there is chemical action going on in the interior of

the earth. Davy, having discovered the alkaline metals, potassium and sodium, found that they possessed such an intense affinity for oxygen, that on coming in contact with water, which we know to consist of oxygen and hydrogen, they decomposed

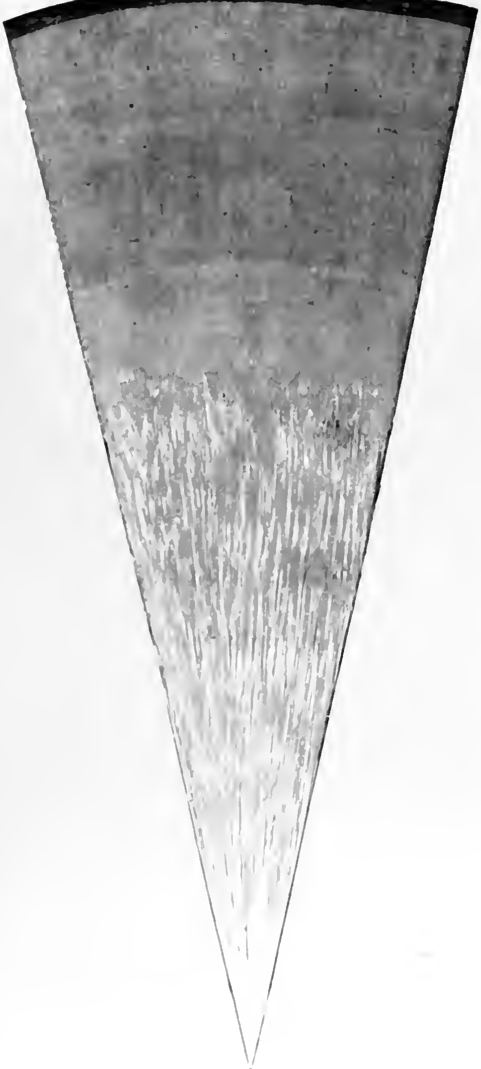

Fig. 3.—Relative Volumes of the Solid Crust and Supposed Fluid Mass of the Earth.

it with intense energy, and, under certain circumstances, with explosive violence. He imagined, therefore, that there was in the interior of the earth large masses of these metals or other substances that acted like them, to which, from cracks in the earth's crust, the waters of the ocean penetrated, when explosions of great violence took place, giving rise to volcanoes, earthquakes, &c., while the rocks around were melted by the intense heat of the chemical combination. This theory, however attractive and plausible, was not borne out by facts. For one thing, if it were true, volcanoes ought to send forth quantities of hydrogen, the product of the decomposition of water, which is not the case. Davy himself had to abandon his theory, maintaining, however, that chemical action still had some part in producing the phenomena.

We are thus left, with our first explanation, in possession of the field. Further consideration will show us, however, that we must modify the picture as there drawn, and that the question is not nearly so simple nor so easily answered as supposed. Indeed, mere inspection of Fig. 2 may suggest to us that the relative thickness of the earth's crust does seem rather inadequate to restrain within bounds such a mass of intensely-heated fluid rock. This idea is greatly strengthened when we consider that this great mass of fluid material is not left quiescent or subject only to its own internal forces, but that it is powerfully acted upon by bodies outside of the earth altogether. In Vol. I., page 204, of this work, in the article "Tides," the action of the sun and moon in producing movements in the ocean is explained. Now, the same principles will apply when the fluid is inside instead of outside the solid.

In the present case, the action will be all the greater from the fact that the ocean of fluid rock is very nearly four thousand miles deep, instead of four miles or so, as the outside ocean is.

If, therefore, the interior of the earth is fluid to the extent supposed, it seems impossible that the comparatively thin crust could control the enormous force of the tides that would be produced.

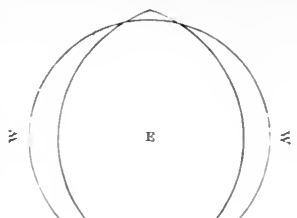

Fig 4.—Showing supposed Effect of Moon upon Conjectured Inner Ocean Fluid.

Let us consider for a moment Fig. 1 on page 205 of Vol. I., and suppose the outer ring W to represent the earth's crust, while the inner space E represents the fluid interior. Under the influence of the moon the fluid would be drawn out into the oblong shape as in Fig. 2 (same page), but in the case we are considering it would be the inner ring that would take this form, and the result would be some such arrangement as the

annexed Fig. 4, where the inner ring bursts through the outer.

From such considerations Sir William Thomson, who has gone very fully into this matter, comes to the conclusion that it is perfectly impossible the crust of the earth can be so thin as hitherto supposed, and that to preserve its symmetry of shape the earth on the whole must be as rigid as a globe of glass of equal size, and possibly as rigid as one of steel.

Sir William further concludes, from a mathematical investigation of the laws of cooling, that the rate of increase of temperature of 1° Fahr. for every fifty feet of descent into the earth cannot continue, but will gradually diminish at depths greater than we can reach as yet, thus placing the point where rock will become fluid at a very much greater depth from the surface than twenty, thirty, or even one hundred miles (Fig. 3).

Another objection to the theory of a fluid interior is this: Considering the earth as at one time fluid to its surface, and gradually cooling by radiation into space, it has been assumed that it would commence to solidify on the outside or surface first, just as water becomes ice first at the surface, and gradually thickens inwards. But it is by no means certain that this would be the case; indeed there is good reason to suppose the very reverse, and that it would first solidify at the centre, and gradually thicken outwards.

The pressure at the centre of the earth we know must be enormously great, and we also know that pressure modifies greatly the temperature at which fluid bodies become solid. Water, for instance, at the ordinary pressure becomes ice at 32° Fahr.; but if we increase the pressure on its surface it becomes solid at a temperature lower as the pressure increases. By enormous pressure it has actually been kept liquid nearly at zero Fahr. Thus the effect of pressure on water is to keep it fluid at a temperature at which it would be solid if the pressure were withdrawn. All bodies that *expand* in the act of becoming solid act like water with reference to pressure. On the other hand, all bodies that *contract* in the act of becoming solid, have the temperature at which they become solid raised by pressure; that is to say, these bodies become solid at temperatures so high that they would become liquid if the pressure were withdrawn.

As the result of experiment, it appears that the rocks of which the earth is composed belong to the latter class, or contract as they become solid, and thus the great pressure in the interior of the earth will tend to solidify them, even although the temperature should be high enough to keep them fluid at the surface.

Let us suppose the fluid mass of the earth just a little above the temperature at which solidification would take place, and then the pressure caused by gravity to be applied. Whether it will first solidify at its centre or at its surface will depend on whether the pressure raises the temperature of solidification at its centre, or its actual temperature at that point higher. If the former is higher, then the solidification will commence from the centre outwards, and there can be no permanent solidification at its surface until all is solid, with the exception, perhaps, of irregular comparatively small spaces. If the latter is higher, then solidification will commence at the surface.

To make this plain, suppose (Fig. 5) a column of fluid, A, B, at a temperature of say 33° all through its mass from A to B, and that the temperature at which it becomes solid is 32°. At some point near the bottom, say at C, let us apply a great pressure. Two results will follow. First, owing to compression, the temperature below C will rise, say to 40°. Second, the point at which the fluid below C will become solid will also be raised; it will not now be 32°, but higher—say 41°. Then, in this case, the fluid will solidify first at the bottom, because there the point of solidification is 1° above the actual temperature, while at the top it is 1° below. Had the point of solidification been raised only to 38° by the pressure, then the top would solidify first.

Fig. 5. Showing Results of Compression upon a Column of Fluid.

Thus we see it is possible and even probable that the solidification of the earth commenced at the centre, and not at the surface.

Further, in the event of the earth solidifying on the surface first, a complete crust could not form all round it, as we know from experiment that the solid rock is denser than the fluid; consequently, it would contract and break up in becoming solid, and sink in the fluid, exposing a new surface to be cooled, and so on till the whole mass was completely solid, or nearly so.

Many scientific men, while fully admitting the force of Sir William Thomson's objections to a perfectly fluid interior, maintain that, although not perfectly fluid, the interior of the earth may be by pressure in a sort of middle state—neither solid nor

liquid, but what is called viscous, like treacle or half-melted wax, on which the tidal action of the sun and moon would have little or no effect. We can easily understand this if we agitate a bowl filled with water and a similar one filled with treacle, when we may observe how easily wave-motion is produced in the former compared with the latter. There is force in this objection so far as tidal action goes, but it does not touch the argument for solidification from the centre.

On the whole, then, we must consider this earth as a globe solid to a very much greater depth than has hitherto been supposed, and possibly solid to its centre. If partly fluid, that fluid must be in a very compressed and viscous state, and at a temperature close to its solidifying point. There probably exist, however, enormous cavities filled with fluid rock which has hitherto escaped solidification from local causes, and exists at enormous pressure, bursting forth in weak places of the earth's crust and giving rise to volcanic phenomena. There may be also, owing to these cavities, movements in the solid body of the earth itself, giving rise by friction to great local increase of temperature and possibly earthquake shocks.

Having thus given an account of the physical condition of the interior of our planet, can we say anything as to its chemical nature? The crust of the earth, so far as we know, is composed of some sixty-four elements or substances which we cannot decompose into anything simpler. Some of these are very dense, such as the metals; others, again, are extremely light, such as the gases. We have seen that the matter in the interior of the earth must be much denser than that on the surface. Now, the question is, whether this great increase of density arises entirely from condensation by pressure, or whether it is partly due to the presence of a greater proportion of the heavier elements. As we have mentioned, Sir Humphry Davy imagined there might be great masses of uncombined metals in the interior of the earth. We have, however, no well-ascertained facts to support this opinion, and must trust, in this part of our inquiry, almost entirely to theory. We need not, however, on that account refuse to consider it, as Theory, if properly founded, is often like the morning twilight of rising science, the precursor of the full light of day.

We have traced the history of this earth back to the time when it was an intensely heated fluid mass; but we may go still further, until we find it as a vapour in the atmosphere of the sun. We know that luminary is a body at an exceedingly high temperature—so high indeed, that metals such as iron, magnesium, calcium, &c., exist in its atmosphere in a state of vapour. It is throwing into space every year an almost incalculable amount of heat, and has been doing so for untold ages. It must, therefore, in former times have contained a vastly greater amount of heat than it does now. We know that heat expands almost all bodies, and consequently the sun must have occupied a much greater space than it does now—so great, indeed, as to have included in its sweep the whole planetary system—the earth, of course, included (Fig. 7)—and, raising them to its own temperature, changed them into vapour so that the whole solar system would exist as a huge nebula or cloud of vapour, similar, possibly, to the nebulæ we see in various parts of the heavens at the present day. As this nebula cooled by radiating its heat into space, it would contract in volume, and in doing so would

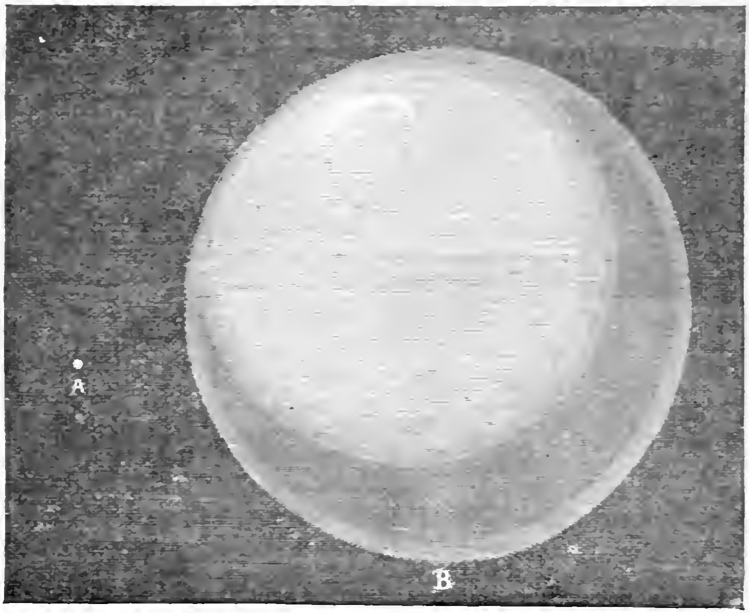

Fig. 6.—Comparative Volume of the Earth in the Solid (A) and Gaseous States (B).

throw off rings of vapour at various stages. These rings, by the action of gravity and centrifugal force, form themselves into spheres or globes which on cooling still further would form the various planets that now revolve round the parent sun. Being much smaller than the main body, they would cool faster and pass first into the liquid and then into the solid form which they now possess. Such is, in brief, the nebular hypothesis which traces the origin of the planets to the great central luminary.

Fig. 7.—The Earth circulating in Space in the Shape of a Gaseous Star.

Although only a theory, it has much evidence in its favour, and completely accounts for the form and physical condition of the earth as regards heat. The evidence of the truth of this theory has been greatly strengthened of late years by the discovery or invention of "Spectrum Analysis," an ingenious process, by the aid of which we know that the elementary bodies which compose the earth's crust exist also in the atmosphere of the sun, and by which we can also ascertain even what the stars are made of.

Admitting the truth of this theory that the earth is indeed of a piece with the sun, we see that the latter is just going through the same process of cooling as the former, only, from its greater size, at a slower rate. From what is going on now in the body of the sun, therefore, we may judge what went on in the earth when it was at the same stage of cooling as the sun is now.

As we have stated, spectrum analysis reveals to us the fact that the same elements which compose the crust of this earth exist also in the sun in a state of vapour. It tells us, however, more than this; it seems to point out how these elements are arranging themselves as the sun cools. It is found on carefully examining the surface of our luminary that the heavier elements are lower down in its atmosphere than the lighter, gravitating or settling down nearer to its centre, so that as the sun solidifies the heavier metals will be found in greater proportion in its interior than on its surface. Should this be found on further and more minute investigation to be a true state of the case, it would go far to prove, or strengthen at least, the idea that the centre of our globe contains a greater proportion of the heavier elements than the surface does. Of course, this is entirely speculation, and must not be accepted as established fact; but

in such obscure and difficult problems every scrap of information is useful and welcome.

We have thus traced to its origin in the far distant past this world of ours, and indicated whence it derived that intense internal heat of which we have such unmistakable evidence. We have shown that it has reached that stage in its cooling when its interior is probably solid to the centre, or, at least, to a great extent, and the remainder filled with greatly compressed semi-fluid material with here and there large reservoirs of completely melted rock which occasionally bursts through to its outer covering. We have also pointed out that its interior may be largely composed of the denser elements, which may act chemically on each other, aiding in producing the high temperature and expansive force we see exhibited in such various ways.

It may be said that the picture we have drawn is so vague and indistinct, and our hope of filling in the details apparently so small, that the inquiry is useless. But it is not so. Already the researches of Sir William Thomson seem to fix, and further researches will probably settle, a time beyond which life could not have existed on the earth. The important bearing of this on such hypotheses as evolution and origin of species, in which something very like limitless time is demanded, is very evident. When we consider also that not many years ago it seemed quite as hopeless that we should ever attain to a knowledge of the elements that compose the sun and stars, and now we not only know that, but are in a fair way of telling the temperature of the sun and the pressure of its atmosphere; when we see such scientific inventions as the telephone and microphone brought out with such startling rapidity; when we bear these things in mind we need not despair of some day having a sort of earth stethoscope by which we may be able to sound its depths and understand its inward workings.

HOW SUNSHINE WARMS THE EARTH.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S.,

Late Vice-President of the Meteorological Society, etc.

IN the preceding paper (pp. 110—117) it has been shown that the interior of the earth is warmer than its outside, or surface, where living creatures dwell. The exact investigations of scientific authorities have amply proved that this is the case. It has been shown that with every fifty feet of descent down into the solid substance of the earth the heat increases one degree of Fahrenheit's thermometric scale. In ages long gone the entire earth was, in all probability, much hotter than it now is, and it has been cooling since that time, as a kettle of hot water is chilled when it is left standing in a cool place—that is, by throwing off to surrounding bodies and space much of the heat which it at first possessed. This process, however, in reference to the earth, has been in recent days a very slow one, on account of the obstacle which the dense outer rocks and beds of the terrestrial substance offer to its progress. A few feet down in the ground the temperature does not now appear to change year after year. The cooling of the earth is at this time, indeed, so exceedingly slow, that for all practical purposes it may be looked upon as having ceased altogether. M. Arago, who had given much careful thought to this subject, held that the actual temperature of the earth has certainly not changed to the extent of one-tenth part of a degree within the last two thousand years.

Upon the immediate surface of the earth there is, nevertheless, change taking place in the matter of its heat from day to day, and from month to month; change, too, which amounts to a very considerable and important quantity. This change, however, is obviously due to an external, and not to an internal, cause. It takes place between day and night, and between summer and winter. The surface of the earth, wherever it is observed, is almost always warmer during the day than it is at night, and it is always warmer during summer than in winter. The changes between day and night penetrate down into the ground to a depth of three feet, but terminate there. The changes between summer and winter penetrate forty feet into the ground, and do not reach farther than that. These facts, familiar and simple as they are, have, nevertheless, served to establish the conclusion, at which men have for some time arrived, that the sensible warmth of the surface of the earth is absolutely and entirely due to the heat which it receives from the sun, and that

the weather and climate at any one place depend upon the method in which the sun's heat is communicated there. The poles of the earth are ice-bound and cold because for a long part of each year they are turned quite away from the sun, and because for the rest of the year they receive the sun's heat-rays from a low elevation in the sky. The equatorial and inter-tropical parts of the earth are frostless and warm because they are never more than the few brief hours of an ordinary night without being heated by the direct blaze of the sunshine, and because during the middle part of each day the sun's heat-rays fall upon them from a high elevation in the sky.

The cold of the Polar regions of the earth is very intense. In the wintering of the exploring ship *Alert*, under the command of Captain Nares, just within the portals of the Great Polar Sea, where frost reigns supreme all the year round, the temperature fell very nearly 74° below the zero of Fahrenheit's scale, or 106° below the point at which water is turned into ice. Even that, however, does not adequately represent what the temperature of the earth's surface would be if there were no sun shine to warm it, because in the cold which was then experienced there were still some dregs of the past summer's sunshine remaining, and there was also some little overflow from the sunshine of happier regions towards the south carried even thus far by the currents of the ocean and by the wings of the wind. In the regions of space, where there is no solid or heat-absorbing substance placed to catch and to be warmed by the radiant sunshine, the cold is almost certainly many degrees below this. M. Pouillet, an altogether competent authority upon such a matter, inferred, from some ingenious experiments which he had devised, that the cold of void external space must be at least 253° of Fahrenheit's scale lower than the temperature of freezing water;* that is, farther below freezing water than boiling water is above it. Such would almost certainly be the condition of things upon the surface of the earth in the entire absence of sunshine.

Recent investigations which have been made in reference to the heat of the sun have demonstrated that every square yard of its radiant surface gives out every hour into surrounding space as much heat as would be generated by burning 13,500 lb. of coal, and as would suffice to drive a steam-engine of 63,000 horse-power for that time. The entire surface of the sun emits in a year as much heat as would be produced by burning a layer of coal seventeen miles deep, spread all over the solar sphere. The proportion of this radiant energy which the earth receives as its share amounts to only the two hundred and thirty millionth part of the whole. But even that is a richly abundant supply for all terrestrial needs. It is enough to melt in the year a coating of ice one hundred feet thick, spread over the entire earth as a uniform shell.

The sun's heat, however, does not fall with equal intensity upon all parts of the earth. Partly because the earth has a spherical form, and partly on account of the way in which its spherical body whirls round upon itself as it sweeps along in its annual path about the sun, some parts of its surface get more of the solar heat than the rest. All the broad zone which lies near to the centre of largest gyratory movement and between the tropics which limit the range of the vertical sun, gets a very large share; whilst the opposite portions, which lie farthest away from this zone, and immediately round the poles of the axis of rotation, receive a share that is relatively very small. The chief reason for this difference is that during the warmest part of each day the sunshine falls more perpendicularly, or directly, down upon the inter-tropical regions than it does at any time upon the poles. Every one is aware how very much more the sun's warmth tells in the middle of a summer day, when the sun is high in the sky, than it does in the early morning, or late evening, when the sun is low. The greater heating power of the more direct sunshine is due to the circumstance that the heat contained in any given breadth of the sunbeams is more concentrated when they fall upon a surface which is transverse, or directly across, the path by which they arrive, than when they fall upon one which is sloping, or inclined, in reference to that path. Thus, in Fig. 1 let A B, C D, be taken to represent a columnar beam of noon-day sunshine falling perpendicularly upon the surface of the earth from C to D; and let E F represent the space upon which a

* It is not possible to arrive at any exact conclusion in reference to the cold of external space; but it is clear from various considerations that it must be considerably beyond that of any temperature that is experienced upon the earth. M. Fourier considered it to be somewhere about −60° Centigrade, or −76° Fahrenheit, which, however, is only about two degrees lower than the cold which was subsequently experienced in the winter quarters of the *Alert* in 1876. M. Pouillet's conclusion from his experiments was that the temperature of interstellar space is certainly as low as −115° Centigrade, and possibly as low as −175° Centigrade. The mean of these figures, and the temperature which may therefore be assumed as probable for space, is −140° Centigrade, or −221° Fahrenheit.

similar beam would strike when it fell slopingly upon the surface from the sun low in the sky, either soon

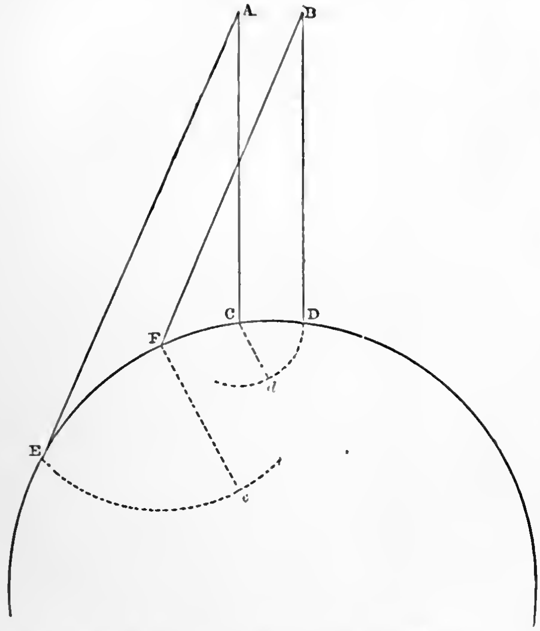

Fig. 1.—Showing the Incidence and Relative Heating Power of the Sun's Rays upon the Earth at Noon and at Early Morning or Late Evening.

after rising in the morning, or shortly before setting in the evening. Then, if the length of the line which stretches between F E be measured off, and a line of exactly the same extent be drawn at F *e*, it will be apparent at a glance that the line F E (or F *e*) is considerably longer than the line C D (C *d*), and that the incident sunshine included within the beam is consequently spread over a much larger space in the case of F E than in the case of C D. The heat carried by the beam is diffused over a wide space in the one case, and concentrated upon a comparatively small space in the other; and it of course tells more in producing sensible warmth when it is concentrated, and tells less when it is more widely scattered. Towards the poles the sunshine never falls otherwise than in the oblique and less heating way at any part of the day. The sun never rises very high in the sky, and for a great part of the year never rises into the visible sky at all. Polar sunshine is therefore at the best in its heating effects very much like morning and evening sunshine at other parts of the earth.

A second influence combines, however, with this concentration of the heating force of perpendicular beams to produce the greater amount of warmth in noontide than in morning and evening, or in Polar, sunshine. Perfectly clear and dry air allows nearly the whole of the heat of incident sunshine to get through without suffering diminution or loss by the way. But air that is laden with moisture, whether in an invisible and transparent state, or in the state of visible mist and cloud, does not permit the same free passage to heat. It stops considerable portions of it by the way, and either imprisons them in itself, or casts them back into outer space. If the line of vapour-laden air through which the incident beams have to pass is a long instead of a short one, then, of course, the effect is so much the greater on account of the length, and still more of the sun's warmth is held back from its proper work of heating the ground or the sea. As a matter of fact, the sunshine does pass through longer lines of air about sunrise or sunset than at noon. In Fig. 2 let *e*, *e*, *e*, *e* be conceived to represent the curve of the solid surface of the earth; and *a*, *a*, *a*, *a* to represent the curve of the outside limit of the investing air, then the line of air through which the noontide sunshine would have to pass would be the short one *a*, *b*; whilst the line of air which the morning or evening sunshine would traverse would be the comparatively long one *c*, *d*. As, therefore, the sunshine arrives upon the ground at morning or evening by a longer

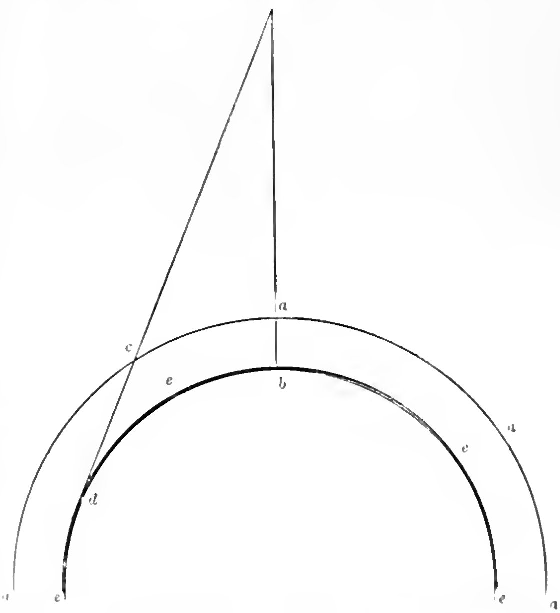

Fig. 2.—Showing that the Sun's Rays have a longer Passage to make through the Atmosphere in the Morning or Evening than at Noon.

air journey than it does at noon, and as it also comes by this longer journey at a time when the air is

generally more heavily laden with moisture or mist than it is at noon, it naturally follows that the sunshine at those times is found to have been deprived of a comparatively large part of its heating power. What is true in the case of the morning and evening is also true of the Polar regions of the earth, and, in a degree, of all regions that have short days and low noontide suns in the winter season.

The fact that pure dry air is freely and almost absolutely pervious to heat is an important and interesting feature in the arrangements of Nature. It is so important, indeed, that a word has been contrived to express this characteristic of air with the sharp precision of scientific definition. It is termed "Diathermancy;"* so that this name stands in relation to heat very much in the same position that transparency holds in reference to light. Diathermancy is sometimes familiarly spoken of as meaning "transparent to heat," and there is no objection to this familiar rendering of the term if it is clearly understood that the heat which has made its way through the permeable substance renders itself "apparent" in the end, by calling up the sensation of warmth in the skin, rather than by producing the sensation of sight in the eye. The *transparency* of the air allows luminous emanations from the external bodies of space to reach the solid surface of the invested sphere. It fits the atmosphere to act as a window to the earth, through which men can look upon the outside regions of Nature, and through which all the gorgeous effect of illumination and colour can come in to stamp terrestrial objects with visible and distinguishable form. To arrive at a clear idea of what the earth would be without a transparent atmosphere, it is only necessary to think of the aspect of London in a thick November fog. So, also, if the air were not as freely permeable to heat-vibrations as it is to light, the earth could not possibly be vivified as it is through the influence of sunshine. It is the heat-vibrations from the sun which stir up the molecules of terrestrial matter to marshal themselves into organised forms, and to carry on the structural transformations upon which vitality depends. Professor Tyndall, by a series of delicate experiments, which he repeated in detail in his lectures at the Royal Institution in 1862, satisfied himself that pure air, and the elementary gases, oxygen and nitrogen, of which air is composed, allow heat-rays of even the feeblest character to traverse their substance, without being deprived of any appreciable portion of their warming power. It is far otherwise, however, with moist air, even when of perfect transparency, and without any trace or taint of visible mist. Air saturated with moisture intercepts and absorbs large quantities of heat; in all cases as much at least as 5 per cent., and in some instances as much as 70 per cent., of that which is thrown in amidst its molecules. Moist air thus serves both to soften the scorching power of hot sunshine which comes in from without, and to prevent the warmth which has already made its way into the solid ground from being too readily and too lavishly scattered back again into outer space. It is for this reason that the sunshine on the tops of high mountains, which are above the chief mass of the vapour that is incorporated with the air, scorches and blisters the skin so much more than the sunshine of the low-lying and moist regions of even the torrid zone. This is a subject, however, which will have to be again alluded to upon another occasion, when the aqueous vapour of the air is more immediately under consideration.

On account of the different heating power possessed by direct and oblique rays of sunshine, inclined surfaces are apt to be more powerfully heated by the sun when at a low altitude in the sky than the more level ground. Thus, if in

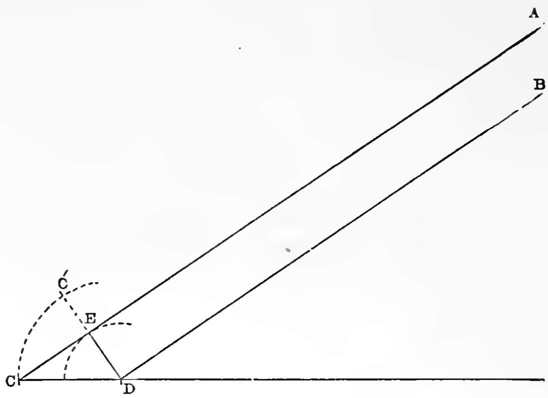

Fig. 3.—Showing that Obliquely-falling Rays are less Concentrated on the Level Ground than on the Sloping Surface of a Hill.

Fig. 3, A B be conceived to represent a beam of incident sunshine falling obliquely upon the superficial space of the horizontal ground extending from C to D, then the same beam would be concentrated upon the shorter extent, D E, of the slope of a hill stretched transversely across the path, and would, therefore, exert more heating power upon it than upon the level ground. D E in Fig. 4 would represent the space upon which the same amount

* Diathermancy: from the Greek διά, through, and θέρμη, heat.

of heat was concentrated in one case, and C D that upon which it was scattered in the other case.

Fig. 4.—Showing that Incident Sunshine is spread over a Larger Area when it falls upon an Oblique Surface than when it falls upon a Perpendicular one.

But the heating effect of the sun does not depend solely upon the inclination with which the sunshine falls on the surfaces that are to be warmed. As a general rule, as has been explained in a previous passage, the equatorial and intertropical regions of the earth are more intensely heated by the sunshine than the poles, or the temperate regions which are intermediate between the tropics and the poles. But the lines of equal heat do not *rigidly* correspond with the circles of latitude upon the earth. Thus, in the chart which is drawn in Fig. 5, the parts of the earth at which the mean yearly temperature of 80° of Fahrenheit's scale occurs are represented by the waving line which runs across from A to B; whilst those at which the mean annual temperature of 60° occurs are indicated by the line running from C to D. The range of the mean yearly temperature of 40° is shown in a similar way by the line from E to F; and of the mean yearly temperature of 32°, by the line passing from G to H.

The reason for this minor irregularity in the distribution of the heating power of the sunshine over the earth, is not, however, by any means difficult to comprehend. The simple fact is, that the sunshine falls on different parts of the earth upon substances which have different capacities for warming themselves by what they receive; and that the heat, therefore, tells more upon some than upon the rest. Thus, for instance, the sun falls in some places upon large stretches of water, and in others upon equally large stretches of land. The

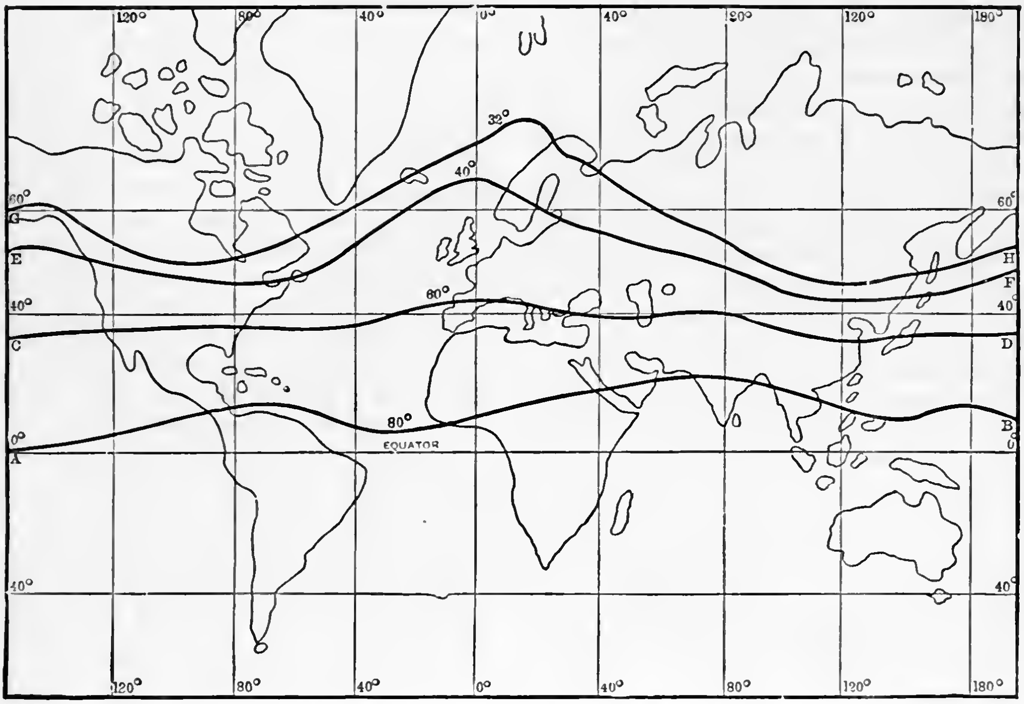

Fig. 5.—Showing the Course of the Curves of equal Temperature upon the Earth.

immediate result of this difference will be seen at a glance if the eye is carried along the line A B of the chart in Fig. 5. That line, it will be observed, touches the equator in the great ocean space of the Pacific, and approaches very near to it in the ocean space of the Atlantic; but crosses the large land space of the continents of Africa and of India, many degrees of latitude away. The range of the mean yearly temperature of 80° lies in higher latitudes over the land than it does over the sea. In other words, the sunshine produces more heating effect upon the solid land than it does upon the liquid surface of the water. Land in reality is heated four times more than water by incident sunshine. The surface of the sea on this account

in no instance exceeds the temperature of 85°; but land surfaces are sometimes heated by sunshine to 140°.

The different extent to which heat takes effect in warming up different substances is determined by two quite distinct influences. In the first place, some substances turn much of the heat which they receive to some other purpose than the palpable and sensible increase of their warmth. This is the case in an eminent degree with water. It requires more heat to warm water up to any given point, such as 80° or 100°, than any other substance which is contained upon earth. But in the second place some bodies take in only one part of the heat which comes to them, and reflect, or throw back, the other parts upon surrounding bodies, or into surrounding space. This occurs, for instance, with white substances, such as snow, white linen, and white paper. If a sheet of white paper and a sheet of black be laid upon the ground side by side in the sunshine, any substance upon which they both rest will be much more rapidly warmed under the black paper than under the white.

The power of water to absorb and dispose of large quantities of heat without acquiring an equivalent increase of warmth is very remarkable. The heat which is sufficient to raise a cubic foot of water one degree would raise 3,080 cubic feet of air to the same extent. This capacity of substances to absorb large quantities of heat into their mass without being equivalently warmed up by its reception is termed, in technical language, their "specific heat." Thus, water is spoken of as having a higher specific heat, or capacity for heat, than mercury; and mercury as having a higher specific heat than air.*

But if water has the faculty of thus taking into itself such enormous quantities of heat, without being warmed in an equivalent degree, it on that account serves as a most convenient and economical reservoir for the accumulated store which has passed into its keeping. It can go on giving back the specific heat which it has received for a very long time before it is exhausted of its ample hoard. In the chart traced out in Fig. 5, the track of the mean annual temperature of 80° on the wide ocean spaces lies very near to the equinoctial line of the earth, because so much of the force of the sunshine goes into the water as "latent" or specific heat, without increasing its sensible warmth; but the same track extends some degrees away towards the north over the continents of Africa and India, because the land in those parts does turn into sensible and palpable warmth pretty well all the heat which falls upon it from the sun. On the other hand, if the line expressing the range of the mean annual temperature of 40° be followed by the eye, it will be noticed that it is carried many degrees farther north over the water spaces of the Atlantic than it is over the land of the western and eastern continents; so much so, indeed, that this seems at first sight to indicate that upon that track the water is more warmed up by the sunshine than the land. That, however, is not the real state of the case. The warmth, which in this instance constitutes the mean temperature of 40°, is *carried up* into the higher latitudes of the Atlantic by a strong ocean current issuing from the Gulf of Mexico, and then passing along the coast of the United States of America, and obliquely across the Atlantic Ocean far on to the north-western shores of Europe, and even to the entrance of the Arctic Sea. This current of moving water receives its heat in the first instance from the sunshine of the Mexican Sea, but then having turned much of what it has received into a specific or latent store, drifts on over the long ocean tract for 4,000 miles before it has expended the whole of this carefully husbanded reserve. Throughout the long stretch of its northward progress it becomes gradually more and more cooled by the slow reconversion of its latent hoard into the sensible state. The air resting upon it above convectively receives all the warmth which it gives out, and in consequence of its own low capacity for latent heat in reality becomes warmed above 2,000 times faster than the water is cooled. In regard to the water itself, the cooling is so slow, under the retentive power exercised by the high specific capacity, that some important part of the warmth of the Mexican sunshine actually finds its way to the portals of the Arctic Sea. A glance at the chart (Fig. 6) will show how boldly the curves of the lines of mean temperature are carried up by this influence into the high northern latitudes of the Atlantic in the cold month of January. The line of the mean temperature of 40°, which falls very near to Constantinople, in north latitude 41°, passes also, it will be observed, over the south-western parts of England, and the northern parts of Ireland, touching in them the parallels of 51° and 55°. The mid-winter climate of England is, from this cause, as genial and mild as the mid-winter climate of the

* The heat which would raise one cubic foot of water one degree would raise thirty cubic feet of mercury to the same extent.

Dardanelles. No more striking and instructive instance could be adduced of the way in which the warmth communicated to the earth from the sunshine is modified and made to tell with less or with greater effect, according to the specific character of the surface upon which it falls.

But the varied distribution of the land itself; the presence of mountains and hills, or of valleys and plains; the predominance of hard bare rock, or of pulverulent, grass-covered soil; the occurrence of broad stretches of dry, barren sand, or of wet

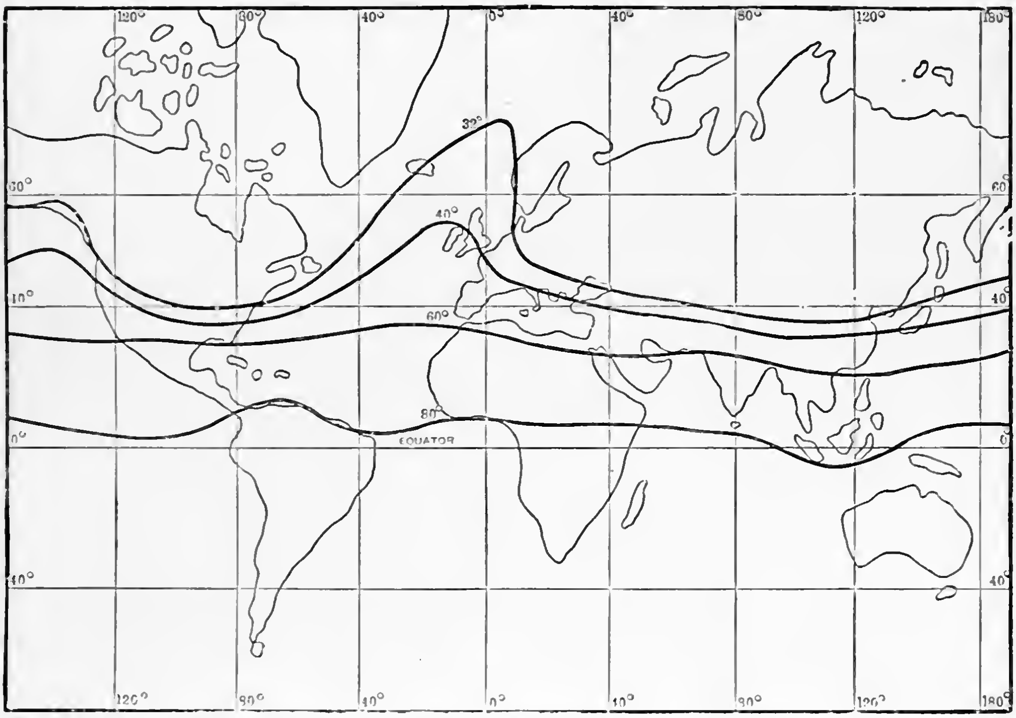

Fig. 6.—Showing the Course of the Curves of Mean Temperature for the Month of January.

bog and marsh; and the existence or absence of broken country, clothed with abounding vegetation, all contribute in a similar way to disturb the uniformity of the heating power of the sunshine, and to prevent the lines of equal mean temperatures from being coincident with the parallels of latitude. The changing altitude of the sun on the noontide sky, with the advance and recess of the alternating seasons of winter and summer, of course, still further exaggerates this irregularity of distribution.

Although pure air is so freely permeable to heat that it allows sunshine to pass through without communicating to it any appreciable portion of its warmth, it by no means follows that air has not a large and important part to play in the ultimate distribution of heat over the surface of the earth. It gets warmed readily in another way, although it is incapable of appropriating transmitted sunshine. When air is placed in direct contact with solid or liquid substances that are warmer than itself, it takes to itself some part of their heat—not by passing it on from molecule to molecule, and so *conducting* it away, as some bodies do; but by *carrying* it bodily off through a never-ceasing succession of particle after particle. At each fresh instant new particles of air come into contact with the warmer surface, and take up as full a load of it as they can individually bear, and then hasten away to afford opportunity for fresh particles to follow in their track, and to assume their share in the work of transport. This method of carrying away heat by successive relays of peripatetic molecules is termed "*convection*," to distinguish it from conduction, in which the heat passes itself from molecule to molecule instead of fixing itself upon molecules, and moving only with them. Moving air or wind, at a low temperature, feels cold when it blows against the warm skin in consequence of this process. Such wind carries away the heat from the warm skin by the continued impact upon it of fresh legions of carrying particles. If air surrounding

the warm body were still, it would keep the heat in, because it could then neither carry nor conduct it away. But air scarcely ever is still. It is itself one of the most erratic and restless of material substances. The entire mass of any extended volume of air consequently gets warmed by the drifting movements of its own molecules in the end, as effectually as it would do if the heat-vibrations could pass from particle to particle. The air drifting above the warm current that ascends from the Mexican Gulf to the high latitudes of the Atlantic, gets heated in this way. It receives, step by step, all the warmth which comes out from the water as its latent and husbanded store is turned back from the latent into the sensible state. The south-west wind which blows from the sun-heated tracts of the Atlantic is thus always a genial, warm wind, when it finally envelopes with its soft breath the hills and plains of England.

There is, perhaps, no meteorological fact which is more persistently illustrated in the every-day experience of life than the truth that the direction and movements of the wind have more to do with the determination of weather than the prevalence or deficiency of sunshine. When the wind passes over any place which is warmer than itself, it takes away with it some portion of the warmth. When it passes over any region which is colder than itself, it gives warmth to that place out of its own superabundance. The south-west wind thus conveys to England in winter time the soft temperatures of the Southern Seas; whilst the north-east wind carries to it the cold of the ice-bound land and snow-covered plains that stretch across the high latitudes of Europe. The sunshine warms the earth, but it distributes and apportions the warmth which it bestows through the agency and instrumentality of the air-currents and the winds. So far as weather and climate are concerned, the sun is the prime source of warmth; but the winds are the administrators of the sunshine.

WHAT ARE THE STARS MADE OF?

By William Ackroyd, F.I.C., etc.

With intense yearning must thinking men of past ages have looked upwards at the starry sky. There in the silent deep, looking deeper and vaster the longer we contemplate it, are the "lamps of the night," each held in its place by some invisible means, each giving out light in some unknown way, each rising and setting with the regularity of the sun. The question would always be recurring, What is a star? and according to the intellectual standing of the self-questioner would the answer vary. The wild red man in the backwoods peoples them to suit his savage but poetic fancy, and even the philosophic dweller in towns thinks they are worlds as material as our own: both, perhaps, deriving their ideas from the occasional landing of a messenger from space in the shape of a meteor. Much of this guessing, however, has been set at rest by the discovery of a means of ascertaining what the stars are; and it is our object in the pages that follow to tell how this has been accomplished.

When we learn anything concerning a terrestrial substance, we have to see, feel, and handle it, and to bring all our senses to aid us in the investigation. Such a course of proceeding is evidently impossible with the remote stars, billions upon billions of miles away, for here only one sense is available—that of sight. Nothing reaches us from any particular one of these bodies but its light, and if there be any secret to discover, it evidently must lie in the star-beams. Now, the unaided eye discerns certain differences in the stars, but certainly not sufficient for us to infer anything regarding their nature and condition. They evidently differ in glory; some are much brighter than others, and in colour they may be white or red, orange, blue, or green. Something more than the eye, however, is needed to see those peculiarities of the light which tell the secrets of the stars. We want a "spectroscope," with knowledge to use it profitably (p. 76). To the uninitiated this instrument appears as strange as its name. Nevertheless, it is really a very simple contrivance for obtaining in a handy form that breaking up of light which in the days of our forefathers and more recent times required a darkened room, closed and hole-perforated window-shutters, prism and screen (Vol. I., p. 192). Let us inquire a little into its history, for no more interesting task can be put to a student of science than that of learning the circumstances of birth,

and the subsequent stages of development, which have given him the instrument in which he takes a pride.

This investigation carries us back to the year 1666. The public mind is still distracted with the roar of Dutch cannon, the echo of which has scarcely left the Thames, and the direful plague is destroying both high and low. A student at Cambridge, not yet 32, although known throughout the world for his splendid discoveries, is deeply bent upon solving another of Nature's problems. Wars and rumours thereof interrupt him not, but he is compelled at length to fly from the plague, and his discovery is not completed until after the scourge has left the land. The man was Isaac Newton: his discovery, the compound nature of white light. Under such circumstances did the spectroscope receive its birth. With a beginning so portentous, the ancients would have predicted some great future; and, however fallacious the grounds for such a prediction, it would for once have been fulfilled. With this instrument millions of miles of space have been set at nought, and the sun and stars analysed; new elements have been discovered on the earth, and fresh fields of research have been opened out.

Before proceeding further, we must say a word as to the meaning of the term *spectrum* (plural, *spectra*), which we have constantly to use. We know that the light of the sun is split up into seven colours by a wedge-shaped piece of glass, and by little drops of falling water (Fig. 1). Now to get a

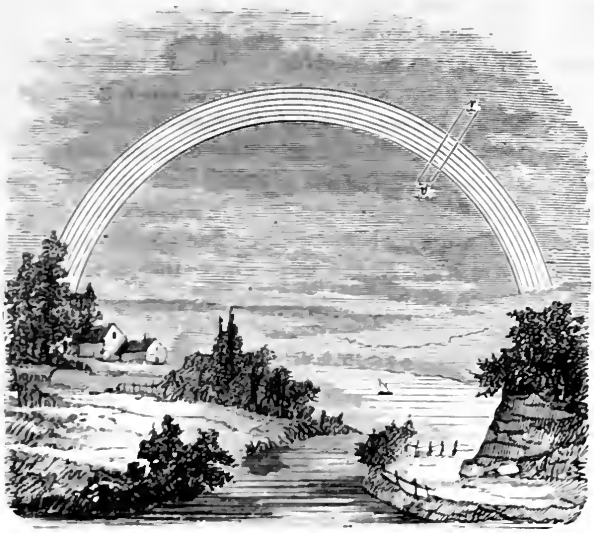

Fig. 1.—To illustrate the meaning of the word *Spectrum*.

correct idea of what the physicists mean by the word spectrum, imagine a slice (r v) to be cut out of a primary rainbow. Such a slice of light is a spectrum. It is a spectrum of the sun's light

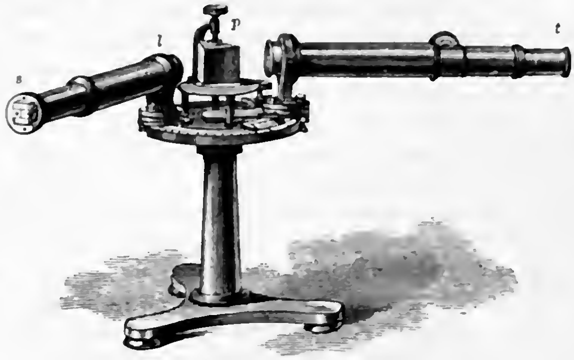

Fig. 2.—Spectroscope.

formed by falling raindrops. With the spectroscope we observe spectra of all kinds of light. To proceed. Recall to mind Newton's famous experiment, and you see at once the principle upon which the spectroscope is constructed. You are in a dark room, and through a single hole in the shutter a beam of sunlight is admitted. A prism—*i.e.*, a wedge-shaped piece of glass—is placed in its path; the light in its passage through the prism is split up into a spectrum, which is cast on to the white wall of the darkened room. In the spectroscope we have a means of performing the same experiment in a compact form. Turn to Fig. 2. The tube (s l) represents the darkened room, and a slit at the end (s) serves for the hole in the shutter. There is a prism (p), and instead of a screen, the telescope (t) which magnifies the spectrum before it is cast on to the retina. The comparison may be made in tabular form:—

Newton's Experiment.	*Spectroscope.*
1. Window shutter with a hole in it.	1. A fine perpendicular slit (s) at the end of a tube.
2. Darkened room	2. Tube (s l, Fig. 2) with slit at one end (s) and convex lens at the other (l).
3. Prism.	3. Prism.
4. White wall or screen to catch the spectrum.	4. Retina to catch the spectrum, after being magnified by the telescope (t).

We need not trouble ourselves here with the various stages of improvement which have given us in the spectroscope such a handy means of performing Newton's experiment. Let us rather make a few experiments with the instrument, to the end that we may learn something of those mysterious bodies, the stars.

Place a candle before the slit at *s*, and having covered the prism with a black cloth, take a peep into the telescope at *t*. You see what might be taken for a slice out of a brilliant rainbow, the spectrum of candle-light. There is no break in the spectrum, it being imperceptible where one colour begins and another ends. Such rainbow slices are called *continuous spectra*, and are characteristic of white-hot liquids and solids. The incandescent carbon in the electric light gives a continuous spectrum, and white-hot metals like iron and platinum give continuous spectra.

Now take away the candle-light, and by means of a looking-glass reflect the light of the sun into the spectroscope. Take another peep into the instrument, and see what the solar spectrum is like. The rainbow patch this time is furrowed with dark lines placed side by side at right angles to the length of the spectrum. A faint idea of the appearance is obtained from Fig. 3.

The court of Belshazzar could scarcely have felt so strong a desire to make out the handwriting on the palace walls as that experienced by the small band of philosophers who studied these lines in the sun's spectrum at the beginning of the present century. Dr. Wollaston discovered them, but there his labours ceased. Fraunhofer mapped them, calling some of the more prominent lines by the letters of the alphabet, and they are now known as *Fraunhofer's lines*. This observer also found the dark lines in starlight, although not in the same number and proportion as in sunlight. Their presence in the spectra of sun and stars seems to indicate that some common mystery hangs around them, and feeling that in solving one we are solving all, we may confine our attention to the sun, which is really a star among the myriads of other stars that people the universe. Here, then, is that peculiarity in the star-beam which will tell us something about the body whence it comes, and to interpret it aright we must again turn to the consideration of spectra we can readily obtain in the laboratory. We want to see now whether we can produce any appearance similar to that presented by the solar spectrum. If we can, it will be of great importance to notice all the circumstances under which the appearance is obtained. With this object we might first observe the spectrum of every available source of light. The electric spark passing through rarefied gas gives a beautifully coloured light. A coloured light is likewise given by various substances when they are thrown into the colourless Bunsen flame, *e.g.* :—

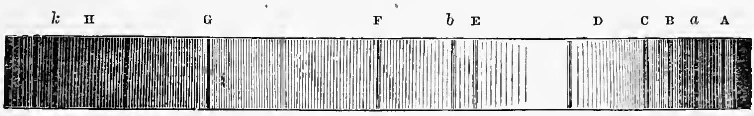

Fig. 3.—Solar Spectrum.

Calcic nitrate	produces a	red light.
Lithic chloride	,,	carmine light.
Strontic nitrate	,,	crimson light.
Sodic chloride	,,	yellow light.
Potassic chloride	,,	violet light.

When we examine each of these coloured lights with the spectroscope, we get a spectrum of bright lines — a discontinuous spectrum, no longer a continuous rainbow-patch, but lines separated from each other, and coloured according to their position. The common salt (sodic chloride), for example, gives one single yellow line; the compound of lithium a red and an orange line; and each of the other substances is distinguished by its characteristic lines. So that if a substance, when put into the flame of a Bunsen burner, gives a yellow line in a particular position, we know we are dealing with the metal sodium; or, if we see the orange and red lines in their proper places, it is certain we have found lithium. Should we see lines in the spectrum that we have never seen before, it is certain we are dealing with some *new* element or compound. In this way our countryman Crookes discovered the metal thallium, which gives in the Bunsen burner a green flame, and in the spectroscope a single green line. Bunsen, a great German chemist, likewise discovered in this way two elements resembling potassium in many respects; and a great many discoveries have been made in this manner.

Now, by what are these line spectra produced? Evidently, in the case where the electric spark passes through a vacuum tube, a luminous gas gives the bright lines, and a little close observation will show that in the other cases luminous vapours produce the line spectra. If one takes a piece of platinum wire, with a loop at the end, and places this loop in the Bunsen flame, with a little strontic chloride on it, a brilliant bright line spectrum is obtained at once; and a few seconds after the crimson portion of the flame is seen to rise from the fused chloride: the chloride is being vapourised, and the luminous vapour gives bright lines. From these facts we learn, then, that the kind of spectrum

depends to some extent upon the physical state of the light-source. A solid or a liquid gives a continuous spectrum; a gas or a vapour gives a discontinuous, or bright line spectrum. Conversely,

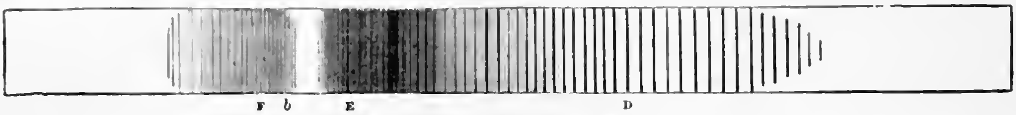

Fig. 5.—Spectrum of Iodine Vapour.

a continuous spectrum indicates within certain limits a condition of solidity or fluidity, and a bright line spectrum a state of gas or vapour.

Besides coloured flames, there are transparent coloured gases, and it will now be of considerable interest to turn our spectroscope to their investigation. They are not sources of light, but evidently have the power to abstract some portions of white light, while the rest is allowed to pass through. Iodine is a substance of this sort. At the ordinary temperature it is a solid of a bluish-black colour, and imperfect metallic lustre. It is most readily converted into a violet-coloured vapour. Take a crystal, and put it into a small flask. Then, by means of the blowpipe, draw out the neck into a fine capillary tube (Fig. 4). If the flask be now warmed, the iodine is vapourised. Whilst the flask is filled with the violet vapour, interpose it between the slit of the spectroscope and a light which gives a continuous spectrum. *Dark lines* are now seen in the spectrum. Fig. 5 is a sketch of the iodine spectrum, at a temperature a few degrees above the boiling-point of water. I employed a paraffin-oil lamp to give the continuous spectrum, and used a spectroscope exactly like that represented in Fig. 2, so that the order of apparatus was this:—(1) lamp; (2) flask containing iodine vapour; (3) spectroscope; (4) eye. The Fraunhofer lines, D, E, *b*, F are given so that the position of the dark iodine lines may be judged of. These Fraunhofer lines are the spectroscopist's sign-posts, and a spectrum of a substance ought never to be given without them. If this point be neglected, much confusion is produced, and in the case under consideration the blue end of the spectrum could not be told from the red by means of the iodine lines alone.


Fig. 4.—Flask for Iodine Vapour.

The vapours arising from strong nitric acid also produce dark lines in a continuous spectrum. To try the experiment, the reader may place a small quantity of the strong acid in a test-tube, and then seal up the upper portion of it with a blowpipe. The portion of the closed tube above the surface of the acid *a b* (Fig. 6) is filled with coloured fumes, which, when examined in the way that iodine vapour was, gives dark lines in the spectrum.

A comparison of Figs. 3 and 5 leads us now to an interesting speculation. Both the spectra agree in having dark lines. Can it be, then, that the sun is a great body, having in itself the power to give out light, and likewise the power to abstract some of this light, acting like the oil-lamp and the iodine vapour together? With this hint, imagination conjures up an enormous white-hot ball to give out a continuous spectrum, and a coloured atmosphere surrounding it to sieve the white light, and produce the Fraunhofer lines. It will be seen in the sequel that this is very near the mark, although not precisely the truth.

Fig. 6.—Oxides of Nitrogen.

The various branches of science stand to each other much in the same relation as the members of a business community. Facts and figures are transferred from one to another to their mutual advancement. In this way the science of light is largely indebted to that of sound; and here again we shall have to draw upon the latter for an illustration which will enable us to get at the precise truth respecting these Fraunhofer lines. Gently press down one of the keys of a piano. Now sing out several notes, one of which is of the same pitch as the note you are fingering. The piano will respond, selecting out of the many notes sung the particular one that would be emitted by the key you have your finger on. To take a simpler example still. Suppose you have two stretched wires before you, both in unison. If you twang one, the other will visibly vibrate; and if the first one be stopped, the second will be heard to give out a weak note. Pitch in sound corresponds to colour in light, and just as a string, capable of giving a note of a particular pitch, will receive that note

from a similar string sounding, and give out the note in a weakened degree, so a source of light of a particular colour will receive light from another source of precisely the same colour, and appear to give it out in a weakened degree—in other words, the vapour of a metal at a lower temperature will absorb exactly those rays which it will emit at a higher. This is the principle enunciated by Kirchoff, and one of his experiments in support of it was this: A continuous spectrum was obtained with the oxy-hydrogen limelight, and a yellow sodium flame was interposed between the light-source and the spectroscope, as in our experiment with the iodine and oxides of nitrogen. A dark line appeared where the yellow luminous sodium line ought to have been. The great importance of the discovery lies in this, that if we have a spectrum with a series of dark lines in it, and we find a metal whose luminous vapour gives corresponding bright lines, then we may safely say that the dark lines are produced by this metal. Turn to the figure of the solar spectrum: there is a double line lettered D. This double line is emitted by glowing sodium vapour. There is sodium vapour, then, in the atmosphere of the sun. The mystery is solved!

The Fraunhofer lines tell us that there are in the atmosphere of the sun, hydrogen, sodium, barium, calcium, magnesium, aluminium, iron, manganese, and a great many other metals. They tell us that the exceedingly hot nucleus of the sun is surrounded by cooler metallic vapours, which are yet so very hot that the metals exist in a state of vapour (p. 77).

In 1861 Huggins and Miller turned their attention to the spectroscopic study of the stars, and some of these, like the stars Aldebaran and Betelgeux, they found to give spectra of dark lines. These dark lines they compared with the bright lines produced by terrestrial substances, finding indications of hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury, in Aldebaran; and sodium, magnesium, calcium, iron, and bismuth, in Betelgeux. These important investigations teach us something positive about the stars: that, like the sun, they have a community of matter with the earth; and that, like this centre of our system, many of them must be sufficiently hot to have metals in the vaporous state which on the earth are solid even at comparatively high temperatures. They may be worlds on the way to become like our own, cool and habitable · and doubtless untold ages ago our earth was in the same plight, this being attested by its present shape, its hot springs and lava-emitting volcanoes.

THE PROTECTIVE COLOURS OF ANIMALS.

By Alfred Russel Wallace, F.L.S., Author of "The Malay Archipelago," etc.

To the ordinary observer the colours of the various kinds of molluscs, insects, reptiles, birds, and mammals, appear to have no use, and to be distributed pretty much at random. There is a general notion that in the tropics everything—insects, birds, and flowers especially—is much more brilliantly coloured than with us; but the idea that we should ever be able to give a satisfactory reason why one creature is white and another black, why this caterpillar is green and that one brown, and a third adorned with stripes and spots of the most gaudy colours, would seem to most persons both presumptuous and absurd. We propose to show, however, that in a large number of cases the colours of animals are of the greatest importance to them, and that sometimes even their very existence depends upon their peculiar tints.

It is an almost universal rule that each animal either has enemies which seek to feed upon it, or that it seeks itself to feed upon other animals. In the first case, it has to escape its enemies or it cannot long continue to live. This it does either by its swiftness of flight, by its watchfulness, or by hiding itself from view. Some species come abroad only at night, some burrow under ground, many hide themselves among leaves, or bark, or stones, and thus escape destruction. Their enemies, however are as swift and as watchful as they are themselves, and they can in most cases only escape them by avoiding observation. To do this, they must not be too conspicuous; and thus any kind of colouring that renders them hardly visible while seeking their food or attending to their young, actually tends to preserve their lives, and often alone enables them to secure the safety of their offspring. But the enemy who is in pursuit of them is in just the same predicament. He, too, must be concealed by his colour, or he will be seen

afar off and his prey will seek a secure concealment. In that case he will simply starve to death, and his race will cease to exist. It thus appears that almost every kind of animal requires concealment; and it might therefore be thought that colour must always be injurious, and ought never to exist. And as colour not only exists, but abounds among the various classes of animals, it may be thought that we have here a *reductio ad absurdum*, and that protective colouring cannot be of much importance. Further examination, however, shows us that even gay colours are very often protective, because the earth and the sky, the leaves and the flowers, themselves glow with pure and vivid hues. In other cases conspicuous colouring is useful to an animal, as when it is protected by the possession of a deadly sting or a nauseous taste, and the bright or unusual colour warns its would-be enemies to avoid it. There are also a great number of animals who appear to be sufficiently able to take care of themselves without resorting to concealment, and with these the tendency to the production of colour, which seems to be inherent in organic beings, exhibits itself unchecked. Taking all these facts into consideration, we find that there is an ample field for the development of bright and conspicuous colour on the one hand, and for the display of an infinite variety of protective tints on the other, dependent on the structure, the habits, and the instincts of the different kinds of animals.

Let us now consider a few familiar examples of protective colouring. Owing to the mildness of the winter of 1877, and the dampness of the following spring, my garden was overrun with slugs, and I had to wage continual war against them. On every damp evening I would go round the borders, examining the choicest plants, and, taking the slugs off with a knife, deposit them in a jar of strong brine. While doing this, many of them, on being touched, would contract and drop to the ground, and though they fell close under my eyes, I often had some trouble to find them again, owing to their close resemblance to the small pebbles with which the soil abounded. They varied in colour from nearly white, to brown, yellow, and nearly black, and when contracted into an oval lump, they were exactly like the variously-coloured wet pebbles. One black slug with an olive-yellow under-surface, when

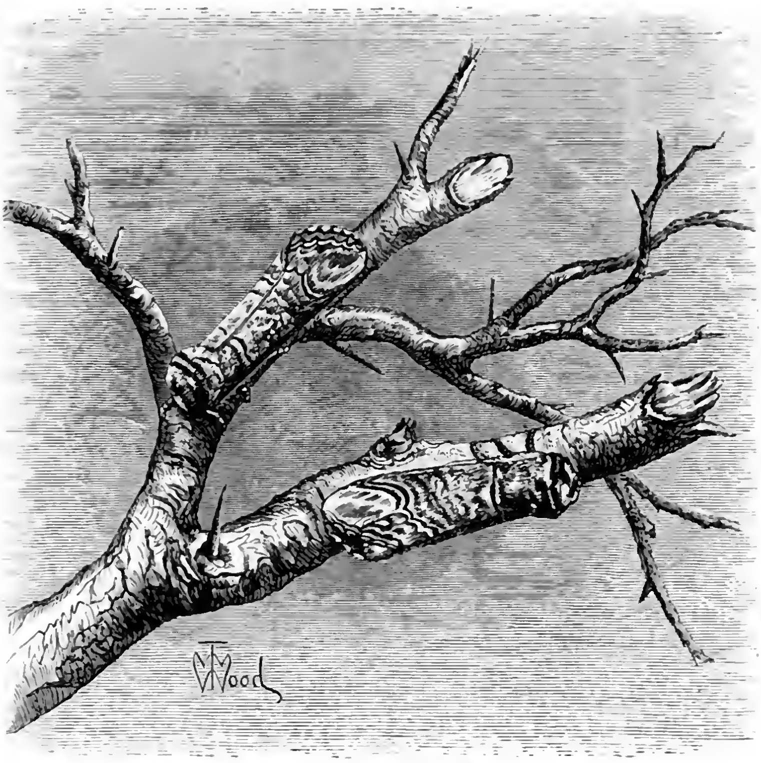

Fig. 1.—The Buff-Tip Moth.

contracted was wonderfully like a blackish flint pebble broken in two, showing the yellowish inside so common in such stones. It may be said that this was only an accidental resemblance, and at first it did not strike me as being anything else; but when, time after time, I lost sight of a slug beneath my very eyes, and had often no other means of finding it again but by touching the various small stones with my knife till I found a soft one, the conviction forced itself upon me that here was a case of true protection, and that what deceived me would also probably sometimes deceive the birds and other animals that feed upon slugs. In the tropical forests I had often in the same way to resort to the sense of touch to supplement that of sight, in distinguishing between the phasmidæ or "stick insects" and real pieces of stick; and as in this case it is universally admitted that the resemblance is a protection to the insects, since it saves them from the attacks of the numerous tropical insectivorous birds, we may well believe that our familiar slugs are similarly protected from the thrushes and other birds which feed upon them.

We will now consider some other cases of protection by colour among animals of our own country, before proceeding to those more wonderful developments which occur chiefly in tropical lands. Every collector of beetles must have observed how many of our *Curculionidæ* or weevils are brown or speckled, and also that they have the habit, on being touched or alarmed, of falling down on the ground, drawing in their legs and antennæ, and there becoming undistinguishable from small lumps of earth or stones. Others, however, which are found

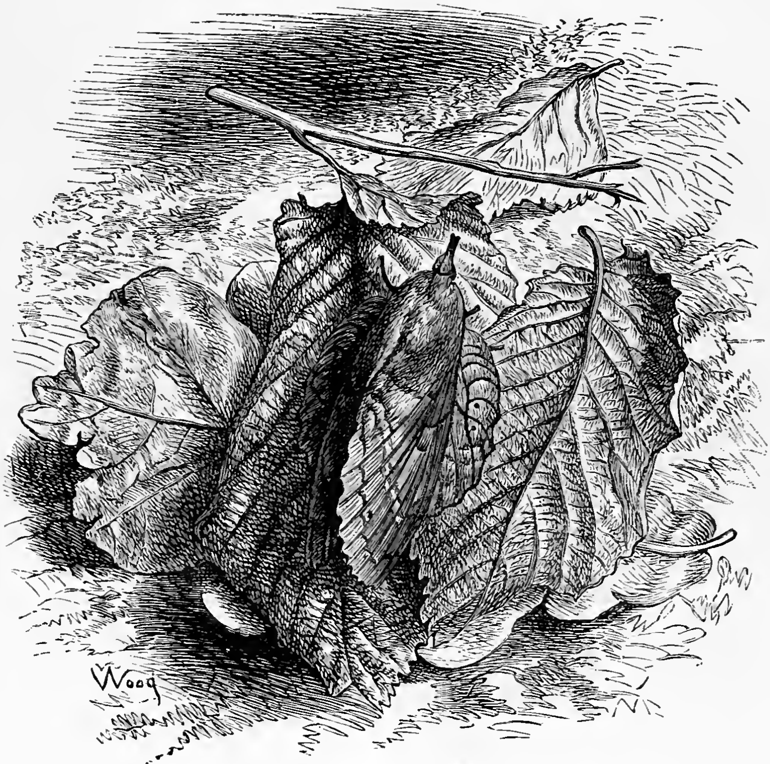

Fig. 2.—The Lappet Moth.

constantly on nettles and herbage, are beautifully green, and these usually run or fly away when alarmed. A curious little beetle, *Onthophilus sulcatus*, is brown and furrowed, so as exactly to resemble the seed of some umbelliferous plant. The beautiful Musk-beetle, which usually rests upon the leaves of willows, is green; while the Saperdas and Rhagiums, which frequent timber or posts, are invariably brown or yellowish. It is, however, among our moths, which are at once more conspicuous and more defenceless, that the best examples of protective colouring in this country are to be found. The beautiful green *Agriopis aprilina* and the dusky *Acronycta psi* rest during

the day on the trunks of trees, and are often completely concealed by their resemblance to the green and grey lichens which surround them. The Lappet-moth (*Gastropacha querci*), when at rest, so disposes its rich brown wings as to resemble, both in shape and colour, a dead leaf (Fig. 2); while the Buff-tip moth (*Pygæra bucephala*) so contracts its wings that it looks exactly like a thick piece of broken stick, the yellow patch at the extremity of the wings giving the appearance of the freshly-broken end (Fig. 1). a leaf, and, *vice versâ*, the dung for the moth. Two other moths, *Bryophila glandifera* and *B. perla*, are the very image of the mortar walls on which they rest; and in Switzerland I amused myself for some time in watching a moth, probably *Larentia tripunctaria*, fluttering about close to me, and then alighting on a wall of the stone of the district, which it so exactly matched as to be quite invisible a couple of yards off." It has also been noticed that the general tints of the moths which are on

Fig. 3.—Jacobeæ Caterpillars.

This is a case which well illustrates how impossible it is to decide from the appearance of a specimen in a cabinet whether the colours of an animal are or are not protective, for no one would imagine that this handsome and conspicuously-coloured moth could ever deceptively resemble a bit of dead stick, and so obtain protection from its enemies. It is a very common thing in the tropics to find beetles and moths which resemble bird's droppings, and the same occurs in this country; for Mr. A. Sidgwick, in a paper read before the Rugby School Natural History Society, says: "I have myself more than once mistaken *Cilix compressa*, a little white-and-grey moth, for a piece of bird's dung dropped upon the wing in autumn and winter correspond to the prevailing hues of nature at those seasons. The Rev. Joseph Greene states that the great majority of the autumnal moths are of various shades of yellow and brown, like those of the autumnal foliage; while the winter moths of the genera *Cheimatobia* and *Hybernia* are of grey and silvery tints.

It is among the caterpillars, however, that protective colouring is the most general and conspicuous. An immense number of these creatures are green, corresponding with the tints of the leaves on which they feed, or brown when they rest on bark or twigs; while a large number of the larvæ of

the Geometridæ or Loopers have the habit of sticking themselves out rigidly like sticks, which they exactly resemble in shape as well as in colour. Every one knows, however, that there are a number of very brightly-coloured caterpillars, and it may be asked how these are protected, or why the others need protection if these can do without it. The answer to this question is most instructive, and affords the most conclusive proof that various examples of protective tints in nature really have the effect we impute to them. It has been found by repeated observation and experiment that every green and brown caterpillar, without exception, is greedily eaten by birds, and even by frogs, lizards, and spiders, and that they endeavour to conceal themselves from these numerous enemies by feeding usually at night, while during the day they remain motionless upon leaves, twigs, or bark, of the same colour as themselves. The brightly-coloured caterpillars, on the other hand, were found to be universally rejected by birds when offered to them, and even by lizards, frogs, and spiders. None of these would touch the common spotted caterpillar of the magpie moth (*Abraxas grossulariata*), nor those of the *Cucullia verbasci, Callimorpha jacobeæ* (Fig. 3), or the *Anthrocera filipendulæ*. Sometimes the caterpillars were seized in the mouth, but always dropped again, as if in disgust at their taste. The same rule was found to apply to all the hairy or spiny caterpillars; and, what is very interesting, the habits of these creatures are correspondingly different from those of the green and brown eatable species. They all feed during the day; they do not conceal themselves, but feed openly, as if courting observation, and secure in the knowledge of their safety from all enemies.*

This connection of gay colours and bold habits with non-edibility, throws light on many other cases of bright colouring which might otherwise be adduced as opposed to the theory of protection. Thus, among our beetles we have such conspicuous creatures as the lady-birds (*Coccinellidæ*) and the "soldiers and sailors" among the Malacoderms, which are all conspicuous and defenceless insects, never hiding themselves, or seeking concealment, or feigning death, as do so many other beetles. The reason is now found to be that, like gaudy caterpillars, they are generally unfit for food. The same explanation may be given of the conspicuous whiteness of certain moths. One of these, *Spilosoma menthrasti*, is very common, but when given by Mr. Stainton to a brood of young turkeys among hundreds of other worthless moths after a night's "sugaring," it was always rejected, each bird in succession picking it up and then throwing it down again, as if too nasty to eat. The same thing has been observed with the showy butterflies forming the family *Danaidæ*. Insect-eating birds were observed by Mr. Belt in South America, catching butterflies which they brought to their nest to feed their young; yet during half an hour they never brought one of the Danaidæ, which were flying lazily about in great numbers.

* For a full account of these interesting experiments, see "Contributions to the Theory of Natural Selection," 2nd Ed., p. 117.

But there are other modes of protection, besides a nauseous taste which renders concealment unnecessary. Either weapons or armour have the same effect, if they are sufficiently perfect of their kind to render it useless or dangerous for their enemies to attack them. The best example of armed insects are the bees and wasps, and among these conspicuous colours are the rule, while they usually fly about and seek their food without any attempt at concealment. Other insects have so hard a covering, or such awkward spines, as to be practically uneatable, and among tropical insects many of these are conspicuously or gaudily coloured. One of the few examples we have of this group are the little Ruby-tail wasps (*Chrysis*) which have no stings, but have the power of rolling themselves up into a ball, which is very hard; and they are so gorgeously coloured as to appear like some curious jewels. Others, again, obtain protection by extreme rapidity of flight, and by concealing themselves in holes or among flowers when at rest, and these are often brilliantly coloured, as in the case of the common Rosechafer. These few examples are merely intended to show that it is no argument against the use of protective colours in some animals, that many others have brilliant and clearly non-protective hues. In those cases, the creatures have certainly some substitute which enables them to live and continue their race. What this substitute is we can in some cases find out, but in many others we are too ignorant of the habits and surroundings of the species to determine whether its peculiar colours are or are not protective, or, if they are not, to determine what are the peculiar conditions which enable it to dispense with this particular kind of safeguard. An excellent example of a brilliantly-coloured insect, which yet obtains protection by its colours, is afforded by the caterpillar of the Emperor moth (*Saturnia pavonia-minor*). The green body adorned with pink spots

is pre-eminently beautiful, and in most situations conspicuous; but it feeds on the common heather, and its colours then so completely harmonise with the young green shoots and small pink flowers, that it is with difficulty detected.

Leaving now these familiar examples, to be found everywhere around us, let us cast a glance over a wider field, and see how the general conditions of existence, affecting many different groups of animals at once, influence their coloration for protective purposes. And first let us transport ourselves to the great deserts of the earth, and inquire what kind of animal life we find there. Canon Tristram has travelled much in the Sahara, and he thus describes the characteristic colours of its animal life: "In the desert, where neither trees, brushwood, nor even undulations of the surface, afford the slightest protection against its foes, a modification of colour which shall assimilate an animal to that of the surrounding country is absolutely necessary. Hence, without exception, the upper plumage of every bird, whether lark, chat, sylvian, or sand-grouse, and also the fur of all the smaller mammals, and the skin of all the snakes and lizards, is of one uniform isabelline or sand colour." This is not a characteristic of one desert, but of all. In a recent account of the Steppe of Erivan in Asia Minor, it is said that "a remarkable feature of the animal inhabitants of the Steppe, insects and reptiles, and especially of the lizards, is the most perfect coincidence of their colouring with the colouring of the Steppe." More prominent examples of this prevalent tint are such animals as the camel and the lion, which are exactly of the usual tints of sand and sandy rock.

Let us go now to the arctic regions, and we find these reddish-yellow tints entirely wanting, and instead of them pure white, or in a few cases dark-brown or black, where conspicuousness seems of more importance than concealment. All the bears of the globe are brown or black, except the polar bear, which is white. The polar hare, the snow-bunting, the snowy-owl and the jer-falcon, are also white or nearly so; while the arctic fox, the ermine, and the Alpine hare, change white in winter, as does our own Highland ptarmigan. This last bird is a fine example of protective colouring, for its summer plumage so exactly harmonises with the lichen-covered stones among which it delights to sit, that a person may walk through a flock of them without seeing a single bird; and when it changes to white in winter it is equally protected amid the snow which covers the mountains. A striking exception to the usual white covering of arctic animals is the Musk-sheep, or Musk-ox as it is often erroneously called. This animal is of a dark-brown colour, easily seen among the snow and the ice, but the reason of this is not difficult to explain. The Musk-sheep is gregarious, and derives its protection from this habit. A solitary strayed animal would soon become the prey of the polar bears or even of the arctic foxes; it is therefore of more importance that it should see its comrades at a distance, and so be able to rejoin them, than that it should be concealed from its few enemies. Another case is that of the sable, which retains its rich brown fur throughout the severity of a Siberian winter, but at that season it frequents trees, feeding on fruits and berries, and is so active that it catches birds among the branches. Again, the common raven is found in the extreme arctic regions, but is always black; and this is probably because it has no enemies, while, as it feeds on carrion, it does not need to be concealed from its prey. These three cases are exceedingly valuable from a theoretical point of view, for they prove the incorrectness of a common notion that animals may change to white in the arctic regions either from the direct effect of cold, or from some influence of the white reflections from the snow; and they teach us that only those animals become white to whom that colour is useful, while those which either do not require protection or to whom dark colours are actually beneficial, remain totally unaffected. The cause of change must therefore be sought, not in the direct action of external conditions, but in the same general laws of variation and selection which have modified all the other characters of animals in the way most beneficial to them.

Nocturnal animals offer equally good examples of protective colouring. Mice, rats, bats, and moles, are all of dusky or blackish hues, and are therefore very difficult to be seen at night; when alone they move about, while during the day they conceal themselves in holes or underground. When concealment by day as well as by night is required, as in the case of owls and goatsuckers, we find dusky mottled tints, assimilating with bark or earth during the day, and not very conspicuous at night. In some few cases nocturnal animals are conspicuous, a striking example of which is the North American skunk, which has much white about it and a large white tail which it carries erect in the most conspicuous manner possible. But the horrible odour emitted by this animal makes it universally dreaded, and its conspicuous tail is thus a signal-flag to all carnivorous animals not to attack it—a parallel case, in fact, to the white moth,

which we have already seen was rejected by birds which eat so many other moths.

Equally striking as a proof that colour is largely protective is the fact, that nowhere but among the evergreen forests of the tropical and sub-tropical zones do we meet with birds the ground-colour of whose plumage is green. Parrots, which are confined to such countries, are generally green, with small patches of vivid colours. In the Eastern tropical islands many pigeons are as green as parrots, and there are numbers of other groups which are of the same colour. Such are the barbets, a family of fruit-eating birds, especially abundant in tropical Asia; the green bulbuls (*Phyllornithidæ*); the Bee-eaters; the Turacos of tropical Africa; the little White-eyes (*Zosterops*) of the eastern tropics; and many other groups. These all frequent thick foliage, with which their colours so exactly harmonise that it is most difficult to detect them.

Contrast these with the ordinary colouring of the birds of the region of deciduous trees, of which our own country is a fair example. Here anything approaching a pure green is unknown, while brown or olive is the almost universal body-colour of the plumage. This is the tint which is least conspicuous among the leafless trees and bushes, which prevail for so large a part of the year, and when the need of protection is greatest.

Among reptiles these protective tints are very apparent. Our lizards and snakes are all more or less brown or olive tinged, while in the tropics alone they are often of a vivid green, exactly corresponding with the vegetation they dwell among. The curious geckos—flat lizards with dilated toes, which cling to the trunks of trees or to rocks—are often finely marbled with green and grey, so as exactly to resemble the lichen-covered surface on which they cling. Some arboreal snakes of the genus *Dipsas* are, however, nocturnal; and these, like all other nocturnal animals which require to be concealed, are of dusky colours, being of various shades of black, brown, and olive.

Many fishes even, present clear examples of protective colouring. Such as rest on the bottom, like the flounder, skate, sole, or Miller's Thumb, are invariably of the colour of the bottom, and often singularly speckled, so as to resemble sand or gravel. Such as swim near the surface of the water are almost always dark-bluish or greenish above, and white beneath, colours which evidently tend to their concealment from enemies in the air above them or in the water below. The brilliantly-coloured fishes from warm seas are many of them well concealed when surrounded by the brilliant sea-weeds, corals, sea-anemones, and other marine animals, which make the sea-bottom sometimes resemble a fantastic flower-garden. The pipe-fish and sea-horses (*Hippocampus*) are excellent examples of this style of colouring. Some of them are greenish, resembling floating sea-weed; but in Australia there is a large species which is covered with curious leafy appendages, and all of a brilliant red colour, and this lives among red sea-weed, and is then perfectly concealed.

It is, however, among tropical insects that the most perfect and wonderful cases of protection by colour and marking are to be found, and a very few examples of these must now be given. The best known and most celebrated are the leaf-insects of the genus *Phyllium*—curious large insects, whose wings and wing-covers are broad and flat, shaped and veined exactly like leaves, while their legs, head, and thorax have all flat dilatations, like the stipules of many plants; and the whole being of the exact green tint of the foliage of the plant they live on, it is actually impossible to detect them when they are not in motion. The walking-stick insects, or spectres, are equally curious. These are long cylindrical insects, often nearly a foot long, and of the exact colour of pieces of greenish or brown sticks. If they have wings, these fold up closely, and are concealed under wing-covers of the same stick-like appearance; while the head and legs are so shaped and jointed as either to fit closely on to the stick-like body, or to appear like branched twigs. These creatures hang about shrubs in the forests, and can seldom be distinguished from small twigs and branches which have fallen from the trees overhead. They remain quite motionless during the day, and feed at night, and they hang anyhow across the foliage, holding on by two or three of their legs only, while the others are closely fitted to the body, and they thus give themselves that unsymmetrical appearance which belongs to accidentally-broken twigs. A few of the species are still further protected by curious green, leafy excrescences all over the body, so as to look exactly like a piece of dead twig overgrown with a delicate moss. Such a one was brought to the present writer in Borneo by a Dyak, who assured him that moss had grown over the insect while alive, and it was only by very close examination that it could be discovered that the supposed moss was really part of the integument of the insect.

Even among butterflies, whose gay colours seem

only adapted to render them conspicuous, there are equally wonderful examples of protective marking. It was first pointed out by Mr. T. W. Wood (to whose skilful pencil we are indebted for the illustrations to this paper) that our beautiful little Orange-tip butterfly (*Anthocharis cardamines*, Fig. 4), although so conspicuous when on the wing, is perfectly concealed when resting in the evening in its favourite position among the flower-heads of the wood parsley (*Anthriscus sylvestris*). Its

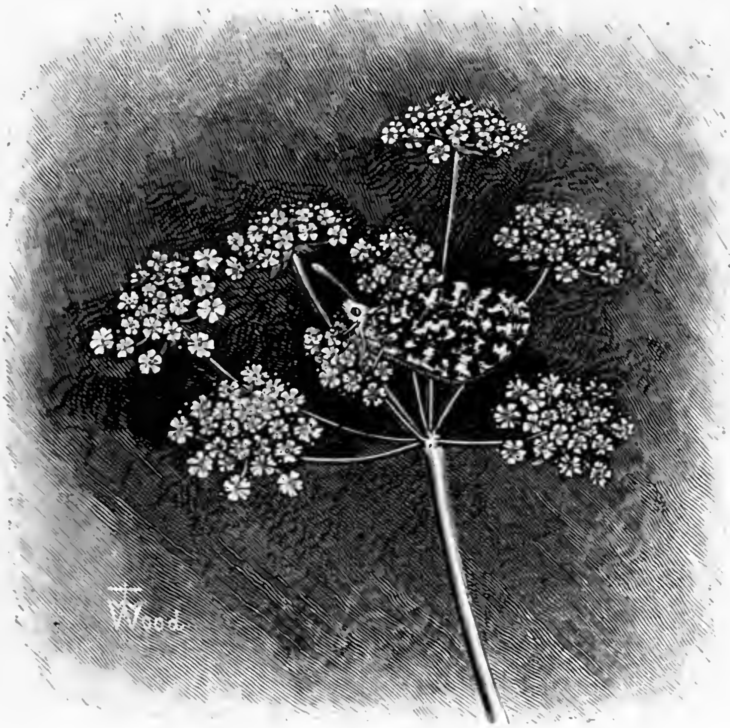

Fig. 4.—The Orange-tip Butterfly.

under surface is beautifully mottled with white and green, which strikingly assimilate with the white and green flower-heads of this plant. Much more wonderful, however, and perhaps the most wonderful of all imitative insects, is the leaf-butterfly of India (*Kallima inachis*, Fig. 5). This is a rather large and handsome butterfly, of a deep bluish colour, with a broad orange band across the wings. It is thus sufficiently conspicuous; but it flies very quickly, and in a zigzag manner, so as to be caught with great difficulty. It is when at rest that it requires protection, and this it obtains by its colour and markings on the under surface, and by its peculiar habits. The upper wings have an acute lengthened apex, which is exactly the shape of the tip of the leaf of many tropical trees and shrubs; while the hind wings are produced into a short narrow tail, which well represents the stalk of a leaf. Between these points runs a dark curved line, representing the mid-rib, and from this radiate a few oblique markings for the veins of the leaf. The colour of the under side of the wings closely imitates that of dead leaves, but it varies almost infinitely through shades of bright yellow, reddish, ochre, brown, and ashy, just as leaves vary in their different stages of drying and decay. Even more remarkable is the manner in which the diseases and decay of leaves are represented by powdered dots and blotches, often gathered into little groups, so as to imitate in a most marvellous way the various fungi which attack decaying leaves. But to render the disguise effective, it is necessary that the insect should assume the position of a leaf, and this it does most perfectly. It always settles on an upright twig or branch, holding on by its fore legs, while its body (concealed between the lower margins of the wings) rests against the stem which the extremity of the tail, representing the stalk, just touches. The head and antennæ are concealed between the front margins of the wings,

and thus nothing is seen at a little distance but what appears to be a dead leaf still attached to the branch. Yet further, the creature seems to have an instinct which leads it to prefer to rest among dead or decaying leaves, which are often very persistent on bushes in the tropical forests; and this combination of form, colour, marking, habit, and instinct, produces a degree of concealment which is perfectly startling. You see this gay butterfly careering along a forest path, and suddenly rest upon a shrub not three yards from you. Approaching carefully, you look for it in vain, and you may often have to touch the branches before it will dart out from under your very eyes. Again you follow it, and mark the very branch on which it has seemed to rest; but in vain you creep forward, and scan minutely every twig and leaf. You see nothing but foliage—some green, some brown and decaying—till the insect again starts forth, and you find that you have been actually gazing upon it without being able to see any difference between it and the surrounding leaves. After repeated experiences of this kind, and knowing exactly what to look for, you are able sometimes to detect it in repose, and are then more than ever amazed at the completeness of the deception, and at the same time profoundly impressed with the protection that must be afforded by this wonderful disguise—a protection whose effect is seen in the wide range and extreme abundance of the species.

In this case, and in that of the moss-covered stick-insect, we see the extreme perfection of imitative colouring; and we can only understand how this has been produced, by always keeping in mind the very much more numerous cases of slight or partial protection by colour or marking. We can only now briefly indicate some of the steps by which such protection is brought about.

Fig. 5.—Leaf Butterfly of India.

None of the characters of animals are more variable than their colours, though this may appear doubtful when we look at the constant tints and markings of so many animals in a state of nature. There is, however, good reason to believe that even, in cases, these variations are constantly occurring, but, owing to the fact that the tint of each animal is useful to the species, all important deviations from it soon die out. Certain it is that almost every domesticated animal varies in colour, and

IDEAL SCENE OF THE LIAS WITH ICHTHYOSAURUS AND PLESIOSAURUS.

these varieties, not being hurtful as in a state of nature, are increased and multiplied without end. Now, if we suppose an animal to suffer from being too conspicuous, any variation of colour or marking tending to make it less conspicuous will give it a better chance of life; and as offspring tend to be like their parents, these less conspicuous varieties will often leave successors similarly endowed; but these again varying, some among them will be still more protected; and thus the protective tints will tend to become more and more perfect in each succeeding generation, till their enemies, finding the pursuit too difficult, will confine their attention chiefly to other species. Then there will be no more change till some new enemy appears, when a further advance may take place till the protection becomes sufficiently perfect to place our supposed animal in a slightly better position than its neighbours.

It has been a difficulty to many persons to understand how such variations could explain the curious cases of the Alpine hare, the ptarmigan, and many other animals which become white in winter only, when the ground is covered with snow and that colour serves as a protection. It has, however, been observed, that a slight seasonal change takes place in many animals. Thus, in Siberia, the wolf, the horse, the cow, the roe, elk, reindeer, and two kinds of antelope, all become paler in colour during winter. Now, if either of these species migrated northward, till it came to inhabit a country where the winter snow remained on the ground for half the year, varieties in which the seasonal change was more and more pronounced would have an advantage, and thus, in the course of many generations, an animal might be produced which changed colour as completely as do the arctic fox or the ptarmigan.

We must now conclude this very brief outline of one of the most curious chapters in natural history. We have shown how varied and how widespread are protective colours among animals; and, if we add to these the cases in which conspicuous colours are useful, sometimes to warn enemies from such as are distasteful or are possessed of dangerous weapons, at other times to aid wandering species to recognise their companions or to find their mates, we shall become satisfied that we have a clue to much of the varied coloration and singular markings throughout the animal kingdom, which at first sight seem to have no purpose but variety and beauty.

GREAT SEA REPTILES.

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Professor of Natural History in the University of St. Andrews.

IN a former article (Vol. I., p. 198) we gave some consideration to those ancient and extinct reptiles which were organised for flight, and are known to geologists as *Pterodactyles;* and on the present occasion we propose to glance at some of the equally strange types of reptilian life which accompanied these forms. If we go back to that epoch of the earth's history which geologists know as the Secondary Period, we find that at that time the great class of the Reptiles had attained its maximum of complexity. It was truly an "Age of Reptiles." Not only was the air tenanted by the weird and spectral Pterosaurs, but huge lizards, of forms now no longer represented, crawled upon the land, and the waters of the ocean swarmed with special and gigantic types of the same class. It is to these last that we intend to confine our attention at present. To study these, the reader must pay a visit to some good zoological collection, or, best of all, to the long and richly-stored galleries of the geological department of the British Museum, where he will find ample material for the reconstruction of these old and monstrous forms of life, and will be able to obtain a clearer idea of their true characters than can be afforded by any mere description. There are not many places in this country where one could hope to collect the remains of these ancient reptiles for one's self, and we must content ourselves here with the endeavour to obtain some general idea of their construction and of their most important peculiarities.

If we take the reptiles which are known to be in existence at the present moment, we find few of these, comparatively speaking, to be organised for a life in the water. Perhaps the most thoroughly aquatic of these are the great sea-turtles, the compressed bodies and flattened paddles of which enable them to make their way through the waters

of the sea with great power and velocity. The great mail-clad crocodiles and alligators of the warmer regions of the world are also largely denizens of the water. In their case, the chief organ of locomotion is the long, vertically-compressed tail, the animal being impelled through the water by the lashing of this formidable appendage from side to side. On the other hand, the limbs of the crocodile do not differ essentially in their structure from those of ordinary terrestrial animals. Thus, a glance at the accompanying drawing of the fore-foot of the crocodile (Fig. 1, A) will show us that all the five fingers are present, that they are distinct from one another, and that they have their usual form, there being no multiplication of the bones of

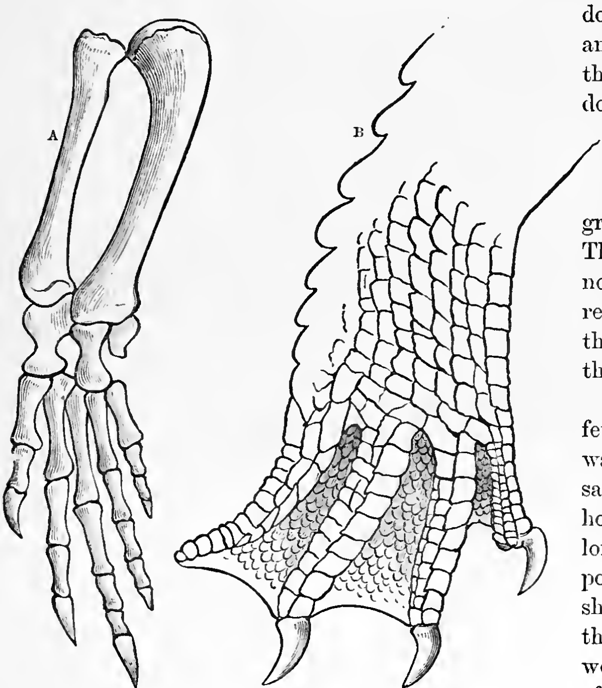

Fig. 1.—A, Bones of the Fore-foot of the Crocodile. B, The Hind-foot of the Crocodile, showing the Extension of the Skin between the Toes.

which they are composed. The crocodile, in fact, uses its feet principally for the purpose of steering, and their efficiency for this purpose is greatly increased by the extension of a loose web or fold of the skin between the toes (Fig. 1, B). In this way the feet are enabled to greatly assist the animal in aquatic progression, at the same time that terrestrial locomotion is by no means entirely precluded, the proverbially awkward gait of the crocodile on land being due rather to the shortness of its legs and the great comparative length and weight of the body than to the actual conformation of the feet.

Not only are the crocodiles thus "amphibious," in the sense that they can either walk upon the earth or frequent its waters at their pleasure, but we may also remember that they are principally—indeed, essentially—frequenters of the *fresh* waters of the regions in which they are now found. They do extend their range to the mouths of rivers, but none of the now existing forms of crocodiles and alligators can in any strict or proper sense be spoken of as *marine* animals.

In addition, however, to the familiar turtles, we have one other group of reptiles which really can be said with propriety to comprise frequenters of the sea—namely, the group of the true Sea-Snakes. Under this head, it is hardly necessary to say, we do not include that apocryphal and mysterious animal popularly known as the "Great Sea-Serpent," the existence of which at all is open to the gravest doubts. On the contrary, the real sea-serpents are in all respects similar to the ordinary snakes, except that their tails are flattened and vertically compressed, enabling them to swim with great ease and speed through the waters of the sea. They are found only in warm seas, and they are by no means remarkable in point of size; while they resemble the turtles in the fact that they betake themselves to the shore for the purpose of laying their eggs.

Upon the whole, then, we have comparatively few reptiles now living which habitually inhabit a watery medium, and of these only a portion can be said to belong strictly to the fauna of the sea. If, however, we trace our steps backwards through the long ages of the past, till we reach the earlier portion of the Secondary period of geology, we should find a very different state of matters. At that time, the ancient Briton, had such existed, would have been confronted with a wide expanse of ocean covering what are now the fair green fields and undulating plains of South-Western and Central England. The old coast-line must have run, roughly speaking, pretty much in the direction of a line drawn from the coast of Dorsetshire to Hartlepool, and to the south-west of this all was open sea, though probably of no great depth. And what a sea for a naturalist to explore! There is plenty to interest the observer in the animals of our own seas at the present day; but one would give much to have had the privilege of living for a few days upon the shores of the south-west of England, at the time when the old Liassic cliffs of Lyme Regis and Charmouth were in process of formation, fathoms deep below the blue waters of the sea.

Such an experience, however, would not have been without its dangers as well as its pleasures, and the most serious of the former would have been due to the presence of the huge and formidable sea-reptiles which swarmed round the shores of Old England at the time of which we are speaking. Some of these were great mailed crocodiles, differing little from the modern Gavial, except that they were organised for an habitual sojourn in the sea; but the most interesting and the most important are the strange extinct types known as the *Ichthyosaurus* and *Plesiosaurus*, to which we may devote our consideration in the meanwhile.

The *Ichthyosaurus* was first brought under the notice of the scientific world, in such a manner that its structure could be at all completely understood, by Miss Mary Anning, of Lyme Regis, to whose long-continued and unwearied exertions geologists are indebted for their knowledge of various other old forms of life. The different species varied much in size, but the larger ones were over thirty feet in length, ponderously and powerfully constructed, and more fully adapted for a life in the water than is the case with any reptiles now existing. From the accompanying engraving of the skeleton of the *Ichthyosaurus* (Fig. 2), it will be seen at imparting to this region of the body an amount and power of movement which would be useless or injurious to an animal living upon land, but which is highly advantageous to those inhabiting water. On the other hand, there is no trace in the Ichthyosaur of anything of the nature of the *scales*, which are so characteristic of the majority of fishes. It is quite certain that had any such structures ever existed, we should ere now have found unmistakable proofs of their existence; and we are therefore justified in concluding that the skin of these ancient reptiles was smooth and naked, like that of the ordinary porpoises and dolphins, rather than that of most of the fishes or of the living reptiles.

The organs of locomotion of the Ichthyosaur, also, differed greatly from those of any known fish or reptile. The principal organ of locomotion was probably the long and powerful tail, to the hinder end of which, there is reason to believe, an expansion of the integument must have been attached, constituting a kind of tail-fin. It is true we have no direct evidence of the existence of such an organ, but our great palæontologist, Professor Owen, long ago drew attention to a curious indirect proof of the presence of such a fin. He showed, namely,

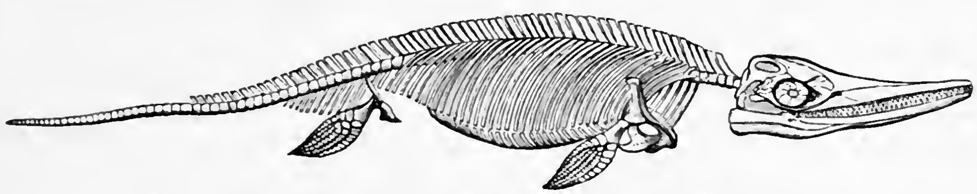

Fig. 2.—Skeleton of *Ichthyosaurus communis*, as restored by Conybeare and Cuvier. (*Greatly reduced in Size.*)

once to what extent the general form of the body is like that of a fish. This is especially seen in the almost total absence of a *neck*, in the popular sense of the term, though this region of the body is anatomically present, as well as in the long and tapering hinder end of the body. The different bones (the "vertebræ") of the back-bone are also fish-like, in the fact that they are deeply hollowed out on both sides, thus becoming biconcave. A glance at the back-bone of any ordinary fish will show that its component pieces are similarly biconcave; and the result of this peculiar structure is obvious. In the living fish, the cavities between the successive vertebræ are filled with a soft, gelatinous substance, and in this way there is formed a succession of loose ball-and-socket joints between the different bones of the spine, thus that the back-bone of the skeletons of Ichthyosaurs, as they lay imbedded in the rocks, was very often found to be dislocated at a point distant about one-third of the total length from the extremity; and he inferred, with much probability, that this commonly-occurring displacement of the bones was due to the presence of a broad and heavy tail-fin, the weight of which would be sufficient to break the continuity of the spine at this point, as the carcase floated at the surface of the sea. That we should not have been able to detect any actual remains of such a fin in the fossils is easy enough to understand, since it must have consisted of nothing more than gristle or fibrous tissue, and it could have contained no bones capable of preservation in a fossil state. In this respect it must have agreed with the tail-fin of the living whales and dolphins,

from which it probably differed in being vertically extended, as is the case with the tail of the fishes.

While the tail, with its terminal integumentary expansion, must have been the principal organ of locomotion in the Ichthyosaur, the limbs were at the same time wonderfully modified to officiate as organs of aquatic progression. Both the fore and the hind limbs were present (Fig. 2), and both have undergone a singular alteration, by which they are turned into broad swimming-paddles, resembling in some respects the "flippers" of the whales and dolphins. If we take the arm and hand of the Ichthyosaur as illustrating this peculiar change, we see that the bones of the upper arm and fore-arm (Fig. 3, *e* and *f g*) are extraordinarily

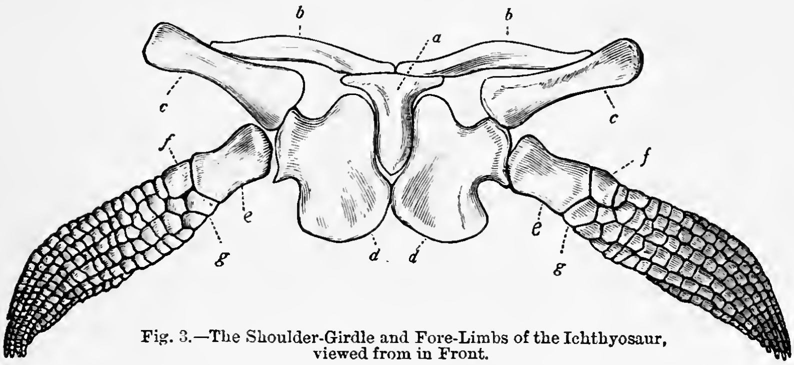

Fig. 3.—The Shoulder-Girdle and Fore-Limbs of the Ichthyosaur, viewed from in Front.
(*a, b, c, d*) Bones of the Shoulder-Girdle; (*e*) Bone of the Upper Arm; (*f* and *g*) Bones of the Fore-arm, followed by the Bones of the Wrist and Fingers.

shortened, while the two latter are followed by a great series of short, squarish, or polygonal bones, which are placed in closely approximated rows, and which together form a broad, flattened paddle, admirably adapted for steering the great reptile through the water. The uppermost of these short bones represent the bones of the wrist, while those which form the free extremity of the paddle represent the bones of the fingers. We thus see, from an inspection of the drawing here given (Fig. 3), that the bones of the fingers are greatly increased in number, when compared with what we see in any ordinary case—as, for example, in the hand of the crocodile (see Fig. 1, A). There is also the peculiarity that the normal number of five fingers is apparently exceeded, this being due to the addition of supernumerary rows of short bones on the sides of the paddles. If we compare the swimming-paddle thus formed with the "flipper" of the whales and dolphins (see Fig. 6, B), it is easy to see that there is a general similarity in their mode of construction, though the fingers in the latter are not closely approximated, and there are no supernumerary rows of bones. The hind limbs of the Ichthyosaur are built upon the same plan as the fore limbs, and similarly form flattened swimming-paddles, the general appearance of which during life must have closely resembled that of the "flippers" of the whales and dolphins, the bones being similarly inclosed in a general covering of the integument, and there being no external and visible evidence of the existence of separate fingers. There is, however, ground for thinking that the integument in the Ichthyosaur was extended to some distance beyond the edge of the paddles as a broad fringe.

Leaving the organs of locomotion, let us look next at the huge skull of the Ichthyosaur (Fig. 4), and the first thing that strikes us is the great comparative length of the jaws, which are prolonged into an extended snout, sometimes five or six feet in length, and have their edges set with numerous sharp, conical, and pointed teeth. These formidable weapons of offence and defence resemble in general points the teeth of the crocodiles, and each, as worn out, is succeeded by a young tooth, which is concealed in the substance of the jaw above its root; but their crowns are furrowed, and instead of being fixed in separate sockets, they are sunk in a long and continuous groove. Next to the jaws, the most noticeable point about the skull of the Ichthyosaur is the great size of the orbits, or the bony chambers in which the eyes were contained.

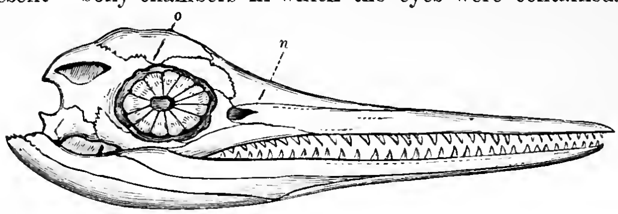

Fig. 4.—Skull of the Ichthyosaur.
(*o*) Orbit, with the Circle of Sclerotic Plates; (*n*) Nostril.

Not only is the orbit of immense size—sometimes over a foot in diameter—but there is the curious feature that the globe of the eye was strengthened by a circle of bony plates situated in the fibrous membrane (the "sclerotic") which incloses the actual apparatus of vision (Fig. 4, *o*). These bony

plates are often preserved in a fossil condition, and from the size of the central aperture which they inclose, we may form some idea of the size of the pupil of the eye, and are enabled to judge that this must have been of large size, enabling the animal to see in the dusk. Similar bony plates are found in the fibrous coat of the eye in birds, and one important function that they discharge is to protect the eye from pressure, as the animal alters the density of the medium by which it is surrounded, by altering its position in space. Hence, it is probable that these bony plates served to protect the eye of the Ichthyosaur from the distorting effect of pressure as it dived below the surface of the water.

Just in front of the orbits are placed the apertures of the nostrils (Fig. 4, *n*), which are thus situated comparatively far back, and not at the end of the snout, as in the crocodiles. Being a genuine reptile, the Ichthyosaur was, of course, an air-breathing animal, and, therefore, it can only be said to be an inhabitant of the water in the same sense that the seals and whales are so also. It was in the water, but not of it. From the great comparative size of the cavities of the chest and abdomen we may infer that it could take in an exceptionally large supply of air, and, being a cold-blooded animal, might thus remain under water for an exceptionally long period of time; but it is certain that it must have been obliged to come to the surface at intervals for fresh supplies of air.

The points which we have now briefly glanced at as to the construction of the bony framework of the Ichthyosaur, have given us a tolerably clear idea as to the general form and habits of these great Secondary reptiles; but we may advantageously summarise some of these. From the general structure of the skeleton, and especially of the limbs, it is quite certain that the Ichthyosaur was an habitual denizen of water; and that it lived regularly in the sea, and not in lakes and rivers is shown conclusively by the constant association of its bones with the remains of sea shell-fish and other unquestionably marine animals. Like the living turtles and sea-snakes, it doubtless sought the shore for the purpose of laying its eggs; and though its swimming-paddles cannot have been specially adapted for supporting such a long and unwieldy carcase upon the dry land, it can hardly have been worse off in this respect than are our modern turtles. That the Ichthyosaur kept principally to the open sea seems probable from the great development of the apparatus of locomotion; while the presence of a ring of bony plates in the outer covering of the eye would appear to indicate a habit of diving to considerable depths, the principal use of such a structure being, as already stated, to protect the eye from increased pressure from without, and thus to preserve the power of vision when the animal was below the surface. That it sought its food principally in the twilight or at night is rendered probable by the enormous size of the eye, which would be unnecessary in an animal habitually active by day; while the fact of its having lived upon other animals is sufficiently proved by the wide gape, the lengthy jaws, and the long rows of conical and pointed teeth. If, indeed, the nature of its dental apparatus had left us in the slightest doubt upon this point, we should have been furnished with conclusive proof of the carnivorous habits of the Ichthyosaur by an examination of the petrified contents of their intestines, which have been often preserved in the rocks, and are familiar to geologists under the name of "coprolites." These singular fossils not only contain a notable amount of phosphate of lime, indicating that they are largely made up of the comminuted bones of vertebrate animals, but they not uncommonly exhibit the undigested scales and bones of fishes. From the occurrence, in fact, of the bones of a small Ichthyosaur within the ribs of a large example of this species, Dr. Buckland was led to conclude that these reptiles did not confine their ravages to their piscine companions, but that they sometimes turned their attention to the weaker and more diminutive individuals of their own kind.

Leaving the Ichthyosaur, let us now look for a moment at its common companion, the curious and gigantic reptile known as the *Plesiosaurus*. That this extinct type of reptilian life was essentially marine, is known by evidence the same in character, and equally conclusive, as that which enabled us to determine the habits of the Ichthyosaur. And yet, with a wonderful similarity in some points of construction, there is a wide difference between these two ancient forms. That the Plesiosaur was aquatic in its mode of life could be safely inferred by the structure of its limbs, even if we were without any other evidence upon the subject. Both the fore and hind limbs are present, and both are converted into flattened swimming-paddles (Fig. 5), this of itself being sufficient proof that their possessor lived principally in the water, and that its visits to the dry land were of a merely occasional and temporary character. There is, however, considerable difference between the swimming-paddles

of the Plesiosaur and those of the Ichthyosaur; and the former makes a much nearer approach in this respect to the structure of the "flippers" of the whales and dolphins than is the case with the latter. The bones of the upper arm and of the fore-arm (Fig. 6, *e* and *f g*) are in all similarly shortened; and the bones of the wrist and of the fingers are arranged in a parallel series of short pieces. In the Plesiosaur, however, though there is an increase in the number of the bones which make up the fingers, the normal number of five fingers is preserved, there being no rows of supernumerary bones; while there is no longer the close approximation and practical union of the digits so characteristic of the Ichthyosaur. Compared, however, with the size of the body—which does not seem to have exceeded eighteen or twenty feet in length—the swimming-paddles of the Plesiosaur are longer and more powerful than in the Ichthyosaur. On looking at the skeletons of these two reptiles, and comparing them with one another, we shall at once discover an obvious reason for this difference. In the Ichthyosaur, as we have seen, the neck is excessively short, and the hinder end of the body was greatly lengthened out, and must unquestionably have constituted the principal organ of progression through the water. In the Plesiosaur, on the other hand, the tail is extremely short, and its functions, as an organ of locomotion, must have been relegated to the paddles, while it can hardly itself have subserved any further purpose than that of directing the course of the animal through the water. Far otherwise is the condition of the neck of the Plesiosaur, as compared with that of its more bulky associate. In the latter, during life, the head must have been continued into the body with as little apparent constriction or line of demarcation as we now observe in the fishes or in the whales. In the Plesiosaur, on the contrary, there was an exceptionally long and flexible neck, composed of from twenty to forty separate bones, and reminding one of the neck of a bird; leading us, in fact, to conclude that "it swam near or upon the surface, arching back its long neck like a swan, and occasionally darting it down at the fish which happened to float within its reach."

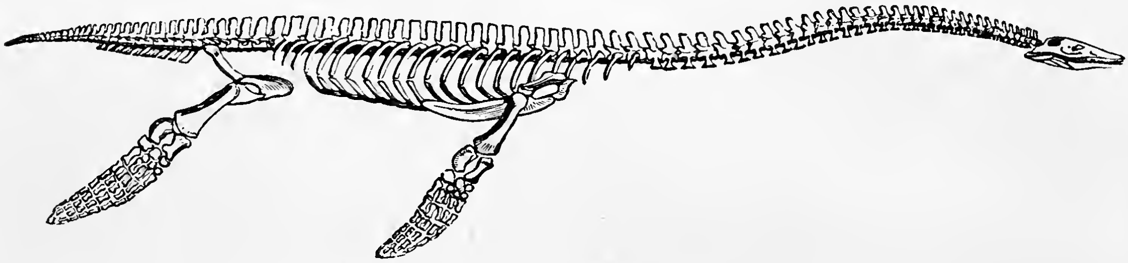

Fig. 5.—Skeleton of *Plesiosaurus dolichodeirus*, as restored by Conybeare.

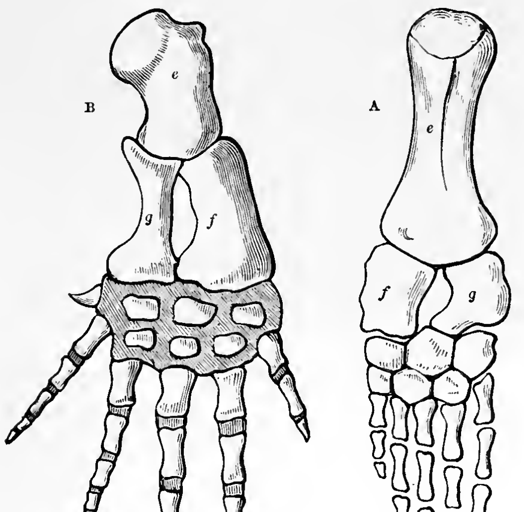

Fig. 6.—(A) Paddle of the Plesiosaur; (B) Bones of the "Flipper" of a Dolphin; (*e*) Bone of the Upper Arm; (*f* and *g*) Bones of the Fore-arm.

That the Plesiosaur was marine in its habits, as before remarked, is quite certain; but its less complete adaptation to a watery medium than was the case with the Ichthyosaur is shown, among other proofs, by the fact that the separate pieces, or "vertebræ" which compose the back-bone are not deeply cupped or biconcave, as well as by the general conformation of the skeleton. It was probably, therefore, rather a frequenter of shallow water, near to the shore, than a denizen of the open ocean. It must, also, have been less conspicuously predaceous than the Ichthyosaur, and must

have lived principally upon the fishes of the seas which it inhabited. This is shown by the comparatively small size of its skull, the much shorter and weaker jaws, and the diminution of the number of the long and pointed teeth. The orbits, lastly, are of moderate dimensions, and there is no ring of bony plates developed in the fibrous covering of the eye; these facts justifying us in the belief that the animal sought its food by day, and that it was not in the habit of diving to any considerable depth.

Space will not permit of our further dilating upon these ancient and wonderfully constructed inhabitants of the sea (Fig. 7), but we have neither exhausted the peculiarities of these, nor reached the end of the long catalogue of the extinct reptiles of the Secondary period. When the white cliffs of Dover were still beneath the waters of the ocean, we meet with other equally marvellous marine types of this great and elastic class—types which may with some reason be regarded as the truest realisation which we are ever likely to have of the popular idea of the "Great Sea-Serpent," though in themselves they were not genuine relatives of the snakes; while throughout the long-continued period of Secondary time the dry land bore its crop of strange reptiles, unlike any that we have now, and yet not wholly unlike. Some of these are of types so unlike any now in existence, that their position in the animal scale could not be safely decided by the isolated relics by which alone we now know them, but can only be inferred from a comparison with other transitional groups. Others, again, belong to orders of which we still possess many living representatives. All alike are of quite exceptional interest to the pure zoologist or geologist, and still more to those who uphold the prevalent doctrine of evolution.

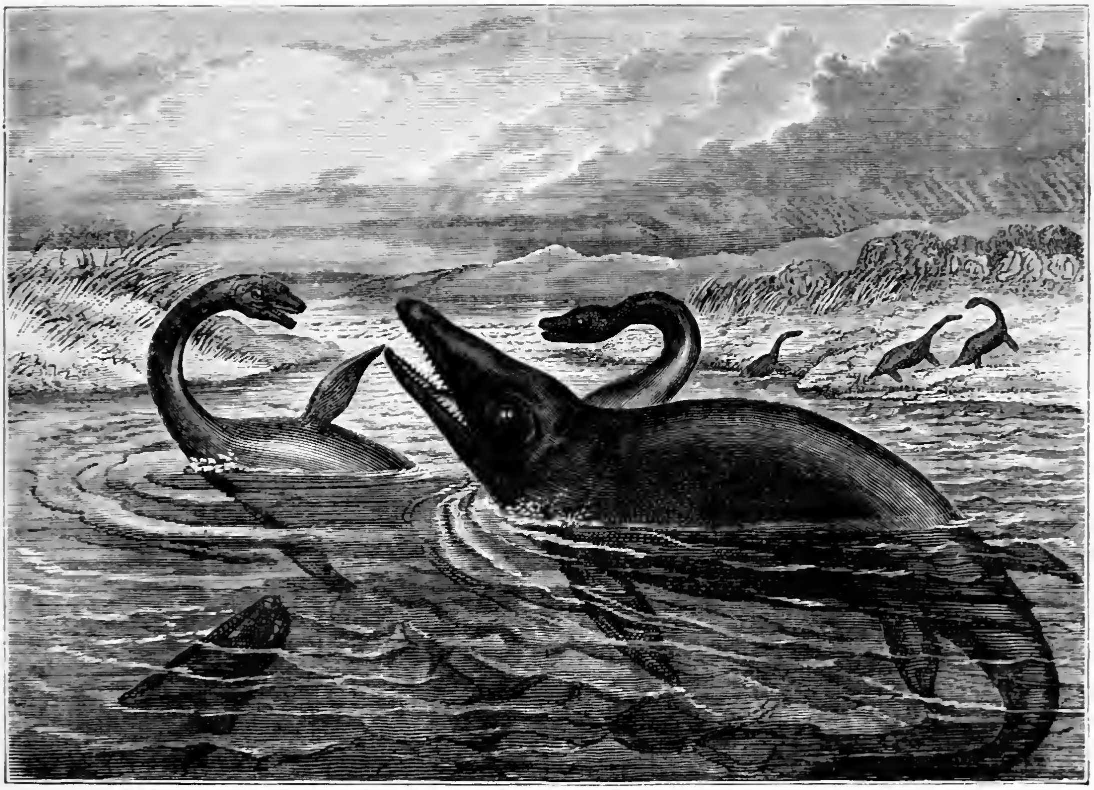

Fig. 7.—Plesiosaurus and Ichthyosaurus. (*Restored.*)

Fig. 1.—Shooting Stars.

SHOOTING STARS.

By W. F. Denning, F.R.A.S.

IF a person will watch the sky on any evening of ordinary clearness, when the stars are shining with some brilliancy, he will observe one or more luminous objects in rapid motion amongst the constellations. These "shooting stars," as they are called, often attract the attention of the most casual observer, either by their frequency or splendour. The suddenness of their appearance, the bright light they sometimes throw over the landscape, the rapidity with which they travel athwart the sky, occasion surprise; and as the observer's eye still lingers on the place of apparition his interest is excited, and questions arise in his mind as to the origin and nature of these remarkable bodies. Whence do they come? Whither do they go? What are their magnitudes, distances, and velocities? If he pursue his observations with any diligence, he will have noticed that they are visible on *every* clear evening; and that, as sure as the darkness comes on and the constellations begin to show, so sure do these falling stars manifest themselves, darting here and there, and exhibiting many attractive features in their unceasing activity. They present every variety of speed and appearance. Some glide along the sky with a slow and stately motion, remaining visible for several seconds, and allow their paths to be conveniently traced. Others are seen to move in extremely quick and transient courses, like flashing rays of light. Some speed along in star-like aspect, devoid of trains or sparks, while others will be seen to leave in their tracks phosphoric lines or streaks, perceptible for some seconds, and distinctly marking the direction of the paths. A few will be noted to move apparently upwards in the sky, and there will be others with nearly horizontal courses; and many will be descending in oblique and vertical paths towards the horizon. Our observer, as he attentively views their irregular and complicated motions, will be impressed that these objects are not following any laws capable of being reduced to the same harmony as pervades the solar system; but he will have formed a wrong idea, for there can be no doubt that they are beginning to be as well understood in their motions and appearances as celestial objects which have been observed from the earliest ages.

By persistent observations, made night after night and year after year, it was found that shooting stars diverged from certain definite points in the sky. Tracing the observed paths back in the same direction of motion, it was discovered that they intersected at a focus, known as the *radiant point.* This

was especially noticed on certain nights in August and November, when meteors were seen in great abundance. No matter in what region of the heavens the meteors appeared, they were all directed from the same part of space, and exhibited many features in common. They converged, like the spokes of a wheel, upon a common centre (Fig. 2). In 1799, on the night of the 11th of November,

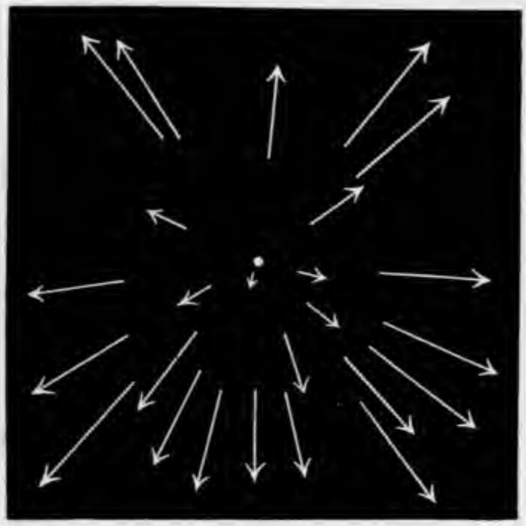

Fig. 2.—Radiant Point of Shooting Stars.

Humboldt, and his fellow-traveller Bonpland, witnessed a great fall of meteors; and in 1833, on the 13th of November, the phenomenon recurred with much splendour, when it was remarked that the vast majority of the meteors had the same point of departure in Leo, near the star *gamma* of that constellation. It was therefore suggested that they belonged to the same system, and occurred periodically at intervals of about thirty-three years, which more recent observations have fully borne out; for on the 13th of November, 1866, there was another brilliant display of meteors. In August, too, on the night of the 10th, a large number of these objects had often been observed. Their apparition on St. Lawrence's Day caused them to be known as "St. Lawrence's Tears;" and it was remarked that in this case the point of departure was in Perseus, and that the phenomenon returned every year with much regularity and intensity: in this respect differing from the falling stars of November, which seemed to be more periodical in character. Another meteor shower of great intensity was witnessed on the 7th of December, 1798, and on the 6th of December, 1838, and the members of these several systems were designated after the constellations from which they emanated. The August meteors are now familiarly known as *Perseids*, the November meteors as *Leonids*, and the meteors of 1798 and 1838 as *Andromedes*.

As observers began to pay more attention to this subject, it was soon found that, in addition to these rich meteoric displays just mentioned, many other systems of a like nature were manifested, though of minor importance. Star showers of more than usual significance had been recorded on the nights of January 2nd, April 20th, October 19th, and December 12th; and as observations further accumulated, it was sought to explain the apparition of these singular objects. Many facts about them tended to puzzle theorists, who had very scanty materials to work upon. When Heis, in 1833, began systematically to observe and record the directions of shooting stars, he entered into an entirely new field of research. Before his time they were seen in a vague, careless way, and seldom recorded with any fulness or accuracy. They were considered to be purely atmospheric phenomena, and of little importance. It is, therefore, not to be wondered at that the ideas prevailing were of the most crude and uncertain nature. Some imagined that they had their origin in phosphoric fluids, which ascended from the earth's surface at various points, and became visible when, having become decomposed in the higher regions, they had taken fire, and the ignition extended itself rapidly backwards to other parts of the column, until it came to a moisture-laden current, which extinguished it. It was further sought to establish a connection between these falling stars and gales of wind, for there are passages in old writers showing the idea to have been very prevalent. Another theory, which also had a section of adherents, ascribed a lunar origin to aërolites and meteors. They were said to be ejections from the volcanoes in the moon, and that occasionally coming within the sphere of the earth's attraction, they were drawn towards her surface. But these ideas gradually gave way to the more reasonable hypothesis that they were of celestial origin, and revolved in orbits around the sun as a centre. To account for their luminous appearance, it was suggested that on entering the earth's atmosphere, as would frequently be the case when the two orbits intersected, the concussion was so great as to ignite their combustible materials, and they were wholly consumed before reaching the earth's surface. The smaller class of these bodies would, no doubt, be soon dissipated in the upper regions of the atmosphere; but it was thought doubtful that the ordinary shooting

stars belonged to the same order as the large meteors and fire-balls, and required the same explanation.

Our knowledge in this branch was, however, most unsatisfactory, when, in 1833, and for several years at about that period, there occurred a succession of remarkably fine meteoric showers, which excited the interest of all ordinary gazers, and, what was of more importance, diverted the attention of astronomers from other subjects. Professor Olmsted witnessed the bright display of 1833 in America, and was led to collect observations made at many parts with the view to throw some light on the subject of these falling stars. His investigations led him to infer that they had their origin beyond the limits of our atmosphere, because the point of the sky from which they fell moved with the stars. If the meteors had their origin within the atmosphere, they must have been carried along with the earth in its diurnal rotation. He also concluded that the meteors were combustible bodies, constituted of light and transparent materials, and said that when massed together they formed a body bearing a strong analogy to a comet. From this he was led to ask whether the meteor shower was caused by a comet which "chanced at the time to be pursuing its path along with the earth around their common centre of motion." Recent researches now enable this question to be answered in the affirmative, for the periodicity and appearances of shooting stars show they are closely allied to comets, and form a number of elliptical orbits or rings revolving around the sun. An actual identity was found between the orbits of several comets and meteor showers. The eminent Italian astronomer, Schiaparelli, showed that the August meteors were directed from a point in the heavens at which the earth encountered the third comet of 1862. The elements of the two were almost coincident; and it was soon afterwards pointed out by Dr. Peters that the November meteors corresponded with the first comet of 1866. These important discoveries lent a new interest to the subject, for they put beyond doubt what had for a long time perplexed astronomers. They had proved that shooting stars played an important part in astronomical physics, coming, in fact, from the interstellar regions, and forming the material constitution of comets. Though extremely small, they exist in planetary space in vast multitudes, and compensate for their smallness of size by their great numbers. The original cometary systems from which they are distributed would appear to be in process of dissipation, or wasting away, for it is impossible to conceive that a body will not suffer diminution when it casts off such a vast number of its atoms as fell towards the earth during, say, the great meteoric shower of November 27th, 1872. But such a process must be very gradual; for though, to our conception, the number of meteors that fall is vast indeed, yet it is trifling when compared to the illimitable supply of the parent systems, and the density with which they are found scattered over a long range of their orbits. Thus, in the case of Biela's periodical comet, which supplied us with the fine meteoric displays of 1798, 1838, and 1872, it is certain that for at least 500,000,000 of miles along the orbit the particles are extended in rich profusion, and sufficient to give a display of much splendour whenever the earth encounters it. Professcr Kirkwood has pointed out that in 1838 the earth intersected a part of the comet's orbit, fully 300,000,000 of miles in advance of the nucleus, and in 1872 the earth was immersed in the rear some 200,000,000 of miles.

It is evident, therefore, that if at a point so distant from the real body of the comet the particles are so thickly strewn as to present showers of considerable intensity, we might expect, in the event of the earth's collision with the actual nucleus of a comet, a meteoric display or illumination far beyond the experience of anything recorded in our annals. The heavens would be alive with the swarming and seething of a vast host of falling stars chasing each other in densely packed ranks, and exhibiting a parallelism of motion most beautiful to behold. Fire-balls of great size and rare brilliancy would be mingled with a thick rain of meteoric dust, suffusing the whole sky. Near the point of space from whence they came, a number of stationary meteors, like transient stars, would be seen; while in a circular area, a few degrees distant, a fringe of meteors would appear with very short paths. Farther off, and in regions removed from the radiant point, none would be seen but those with long, graceful courses; and these would exhibit greater speed than the rest, and generally be more conspicuous. Never more than on an occasion like this should we be thankful for the protection afforded us by our atmosphere, which would be certain to act as an impenetrable shield, and destroy by combustion the meteor particles as fast as they came on. Evidently, therefore, the earth could suffer little in an encounter with a comet; the latter would be certain to get the worst of it. Not only would the comet experience a considerable loss of its materials, but its path must be greatly affected

by the earth's powerful attraction, and henceforward it would pursue a new orbit; for we know that cometary motions are much liable to perturbations if they approach near a planet. Jupiter is a frequent disturber of cometary orbits, for his great mass cannot fail to exercise itself strongly upon the light and thin materials of their composition. But though the earth has never yet been known to meet with a comet, the great meteoric storms that have sometimes been witnessed were signs that a comet was not far off. There is, however, nothing impossible in such an encounter, though it is highly improbable; and some alarm was created in 1832, when it was announced that the nucleus of Biela's comet passed within 20,000 miles of the earth at a point which the earth would occupy on the 3rd of

Fig. 3.—Meteor of Nov. 12, 1861. (*Webb.*)

December in that year: but the comet arrived at the place about a month before the critical date, and hence a collision was avoided.

It has been stated that certain of the principal meteor showers agree in the most conclusive manner with the orbits of periodical comets. This is the case in regard to the meteors of April 20, August 10, and November 13 and 27. But it must not be assumed, therefore, that all the phenomena of falling stars are to be explained at once on the same grounds. Certain anomalies have been pointed out, which render it difficult to harmonise theory with observation. In the cases alluded to, not even the most sceptical would fail to admit the wonderful agreement in the meteor and comet orbits, and must accept the identity as beyond question; but in a vast number of other instances no such excellent coincidences are to be met with. The observed duration of many showers is far beyond the limits assigned to them by theory. Those who have worked most diligently in the department of observation affirm that some of these meteor systems continue visible for a month and more. In some cases, indeed, the time extends over two months, and even beyond that occasionally. Now, it is certain that a meteor shower brought about by the intersection of the earth and a comet's path can last only a few days (except in a special case, when the duration may be longer), and that there will be a short period of maximum intensity. The earth in her orbit travels over about one and a half millions of miles in a day, and hence must very soon make her passage through the meteor stream, unless it has far wider proportions than is considered probable. In the case of the several systems specially referred to as agreeing with comets, the shower of meteors is of very short endurance, and seldom exceeds one or two nights in its real intensity. They conform precisely to what theory teaches. But how shall we explain in the same way a meteor shower continued during two months? Obviously the observations are false, or theory requires modification. The difficulty may, to some extent, be got over if it is granted that these meteor streams have each become scattered, or widened out, over a vast space by the annual effects of the earth's attraction as she sweeps through them. This having been going on for many ages, it is probable that they must suffer considerable distortion; and if this is what has actually taken place, without any material displacement of the radiant points, we can understand how these long-continued showers have their origin. At present, it has been attempted to account for them on the supposition that each one consists of several distinct systems succeeding each other from the same directions, but the explanation is untenable in the face of the numerous and exact observations supporting a contrary view. Meteors are frequently seen coming from the same points in the sky for two months, almost without apparent cessation, and it is only fair to conclude that they belong to the same parent system. If our present ideas as to the nature of meteor orbits cannot explain, then they must be remodelled on the basis of observed facts. It will never do to make observation subservient to theory, or we shall have a bad precedent, and one

which can only tend to stultify original research. Our knowledge in this department is admittedly very recent and incomplete. We must continue for many years to gather materials, taking as little as possible for granted, and bearing in mind that there is great variety displayed throughout the planetary system, and that in the vast assemblage of meteor swarms enveloping the earth we may find many varieties of orbit and origin. There may be terrestrial meteor rings that have an analogy with the zodiacal light. The planets Jupiter and Uranus have each their families of comets, and it is possible that the earth is attended by a number of the same bodies, the scattered and attenuated nature of which place them beyond the range of visibility. Evidently, we have much to learn about these shooting stars and about their allied comets; and he is wise who works and waits, without a too hasty assumption of knowledge that we do not possess, or a too ready broaching of theories based on insufficient materials.

It was long known, before the fact of a connection with comets was ascertained, that shooting stars moved with planetary velocity, and that their average height above the earth's surface was less than 100 miles. The same meteors were occasionally observed at two different stations, and the paths, when compared, showed a large displacement or parallax, and the amount of this afforded a ready means of calculating the meteor's height above the earth, the actual distance (forming the base line) separating the two observers being known. Brandes found, as early as 1823, that of 100 shooting stars seen, twenty-two had an elevation of between twenty-four and forty miles, thirty-five between forty and fifty miles, and thirteen between seventy and eighty miles. Of sixty-six shooting stars recorded in August, 1863–71, Professor Herschel determined the average heights as seventy-eight miles at first appearance, and fifty-three miles at disappearance, giving an elevation of sixty-five and a half miles at mid course. The velocity of a similar number of meteors he found had an average of thirty-four and a half miles per second. Heis's work, embracing a summary and analysis of forty-three years' observations, gives the heights of 262 shooting stars. The largest number first became visible at sixty-seven miles, and disappeared at forty-four miles. The several results show differences, but it must be remembered that these bodies vary a good deal in their heights and velocities. The latter element depends upon the position of the meteor orbit with respect to the earth at the time of intersection. If the meteors are coming directly from that point towards which the earth is moving in her orbit it is evident that they will be of extreme swiftness, because their orbital speed is increased by the earth's, which corresponds to eighteen and a quarter miles per second. The *Leonids* of November nearly fulfil this condition, and their calculated speed is forty-four miles a second. On the other hand, meteors coming from a stream pursuing a similar course to the earth will be characterised by slowness of motion, because they have to overtake the earth, and their orbital velocity is lessened by the amount of the earth's velocity to the extent before mentioned. The *Andromedes* (or meteors of Biela's comet), visible on November 27, partake of the latter class; hence their calculated speed is only twelve miles per second. Thus it is evident that the

Fig. 4.—Luminous Trail left by the Meteor of Oct. 19, 1877.
First Effect. Second Effect.

apparent velocities of shooting stars depend in great measure upon the angles at which they meet the earth.

It is difficult to select, from amongst the large numbers of known meteor systems, those which afford the most conspicuous displays, but it is believed that the following short table comprises many of them. The positions are given in right ascension and declination.

Jan. 2—3 . . .	234° + 49°	July—Aug. . .	309° + 48°
Jan.	230 + 30	Aug. 10 . . .	44 + 56
Jan.—Feb. . .	180 + 35	Aug. 6—12 . .	96 + 72
Dec.—Feb. . .	131 + 48	Aug.—Sep. . .	335 + 52
Feb.—Mar. . .	180 + 56	Sept. 1	306 + 54
Feb.—Mar. . .	175 + 14	Sept.—Oct. . .	46 + 35
April 19—20. .	272 + 35	Sept.—Dec. . .	83 + 50
April—May . .	204 + 56	Oct. 18—20 . .	90 + 15
April—June . .	235 + 23	Oct.—Nov. . .	60 + 20
May 2	326 — 2	Oct.	107 + 25
July—Aug. . .	6 + 37	Nov. 13 . . .	149 + 23
July 27—29 .	341 — 14	Nov. 27. . . .	25 + 43
July 30—Aug. 1	32 + 53	Dec. 6	80 + 23
July—Aug. . .	282 + 60	Dec. 9—12 . .	105 + 32

The durations must be regarded as very uncertain.

As to the number of meteors a person may expect to see on ordinary nights, Schmidt and

several other observers have given the horary rate for each month in the year, but their figures are much below the true values. Ten per hour in the evenings and nearly seventeen in the mornings are the average numbers found by the writer, from observations of 3,323 shooting stars during the last six months of the years 1876—78. For the first half of the year the figures will be somewhat less. In the morning hours shooting stars are very frequent, as a rule, and occasionally fall in unusual numbers.

Fig. 5.—Fire-ball of Sept. 7, 1875. Meteor of Nov. 27, 1877. (Observed by H. Corder at Chelmsford.)

The same systems supply large and small meteors. Fire-balls (of which examples are given in Figs. 3, 5, and 6) intersperse with the most minute of these objects. As to their actual size, little can be ascertained with certainty. It is difficult, especially in the case of bright meteors, to separate angular diameter from the effects of "glare." The fire-ball of November 23, 1877, was estimated to have an apparent diameter of half a mile, but the solid nucleus must have had vastly smaller dimensions. The ordinary class of shooting stars are extremely small, and are conspicuous more from their light than size. Observations, a few years ago, placed the weight of twenty of these bodies as varying between 30 grains and 7½ pounds. The number of small meteors also vastly exceeds those of great brilliancy. In the catalogues of meteor observers they are classed according to their brightness, as compared with star magnitudes. The writer, in order to determine the relative percentage of the various magnitudes of meteors, sorted out more than 50,000 shooting stars in various lists, and found that the best observations showed the following average proportions :—

Exceeding 1st magnitude.	Equal 1st mag.	2nd mag.	3rd mag.	4th mag. and below.
3·0	10·6	18·4	26·2	41·8

The results indicate a progressive increase of 7¾ per cent.

It is often asked, What becomes of the vast number of falling stars which enter our atmosphere? It is impossible to conceive that they are utterly dissipated and vaporised in the upper regions. The probability is that after combustion they are frittered into dust, which slowly subsides upon the earth's crust; for it has been shown, that though many of the particles of dust that are always floating in the air rise from the soil, some display a peculiarity of composition and form strongly suggestive of a celestial origin. A fall of "cosmical dust" has been inferred from the investigations of several scientists, whose conclusions appear to be that iron is mingled with the dust that has been accumulated in church towers by the winds of ages, and that this iron, as it floats in the air, is often trapped in its fall by snow, which frequently gives traces of it. In 1875 and 1876, a quantity of dust was collected from the towers of cathedrals and other elevated positions, and placed under chemical and microscopical analysis. The application of a magnet proved it to contain minute spherical corpuscles, with a slight roughness, which made many of them bottle-shaped. Snow was also collected at many places in France, and by Nordenskjöld in the arctic regions, care being taken to avoid the lower and upper layers, and the presence of iron was detected in each of the residues, and there were irregular particles which were influenced by the magnet. A continuous fall of cosmical dust of meteoric origin seems to be the probable inference from such inquiries, and the further development of labours in this direction may open out some interesting points and explanations in regard to many observed phenomena.

Fig. 6.—Fire-ball of Oct. 7, 1867.

CONTINENTAL ISLANDS, AND HOW THEY WERE FORMED.

By Professor P. Martin Duncan, M.B. Lond., F.R.S., F.G.S., etc.

MOST people who travel, occasionally find themselves on an island; and those who do not, may still have the opportunity of seeing the cliffs of Calais from the English coast, of observing the Isle of Wight, and of tracing the outlines of the bold hills of some of the islands, far out at sea, to the west of Scotland. The sea intervenes in all these places, between the more or less distant land and the observer, and its floor is deeper down—usually midway—than elsewhere. Were it not for this sea, and the trough over which it rolls, the lands would, of course, be continuous. The landscape is much the same on both sides of the Channel near Calais and Dover, and on the mainland and isles of the West of Scotland; and a very slight amount of attention will show that the earth composing the separated districts is of the same kind. The impression is given to the mind that the sea has been an invader of the land, and that France and England, the Isle of Wight and the mainland, and the isles of the West of Scotland and the mainland, were once united. Certainly the separation is increasing, for year by year the cliffs of the south and the bold rocks of the north-west, are worn and gradually removed by the winds and waves and tides; and this adds to the belief in their former union. Some hours of rapid steaming pass, before the Irish coast is reached from the West of England. Deep water is passed over, and the green island is seen sloping up from the depths in some places, and, if the voyage is extended, precipitously in others. Travel over the country, and the sea is seen breaking, more or less, all around its coast. On the west of the island, where the swell of the Atlantic comes on to the shore and rocks, often with almost irresistible force, there are traces that the land once extended where there is now sea, for a broad submarine flat slopes very gradually into the Atlantic; and there are, moreover, some rocks which are standing away from those of exactly the same appearance and height on the mainland, and which in some instances are sufficiently large to be called isles. In the case of Ireland there is not much difficulty in believing that it was once more extensive than it now is, and that its western coast was once far out where the Atlantic now rolls, and that its north-eastern part must have reached far towards the formerly nearer Scottish coast. But there may be some difficulty in the mind of any student who may cross the Irish Sea in believing in the former union of Ireland and England, much as he might desire it, at the present time.

But it might be urged that as the coast-lines of both countries are now wearing away, Ireland and England were once no more separate than Anglesea and North Wales; and as the Menai cliffs do wear backwards, he might conclude that in the distant past the sea began to make inroads and disunite the lands.

The present rate of coast-wearing would, however, be insufficient to account for that of the great mass of intervening land, unless an enormous lapse of time can be admitted to have taken place since the separation commenced. One thing strikes everybody who rambles over England and Ireland, and it is, that there are in both countries plenty of the same kinds of wild flowers, of small birds, and of not a few little wild animals which could not by any possibility float, fly, or swim across the Irish Sea. Either they were created and placed on both countries, or they were once on a common land which has been separated into two. There are some skeletons of large animals found in England and Ireland, in situations which denote that the surface of the countries and the climate have been very different to what they are now, and just before the possessors of the bones lived and died. The animals were gigantic, and their kinds no longer live on the face of the earth. The mammoth, a large kind of elephant, and the megaceros, a kind of elk (Vol. I., p. 286), were amongst them, and it is quite evident that they swarmed over Ireland and England. It would appear that they could not have lived in Ireland or in Western England during the duration of the particular climate just alluded to as existing before the days when their bones were buried by Nature in British and Irish soil, and it follows then, that the mammoth and elk could roam where the great sea now rolls.

In the English Channel there are some relics of the former land which once connected this country with the Continent. The long lines of the Goodwin Sands, and also of the "Gallopers," are founded on chalk, which was worn down and planed by the sea as it invaded the land centuries ago, but which was once hill and dale, like the neighbouring

country. Similar intermediate worn lands are to be found elsewhere, and their place is often occupied by rocks which have not yet been worn away, and which once formed part of the mainland, or by little islets, like those of Scilly, which evidently have been separated from the mainland, comparatively lately in the geological history of the world.

It appears from these considerations that when two tracts of land, however different their sizes may be, are separated by sea, their former continuity may be shown by probable evidence of the most satisfactory kind, and which is founded on the value of the observations that the scenery of both places is much alike, that they consist of strata which were once continuous, that animals and plants which cannot move over the sea are common to them, and that the wear and tear of their cliffs is still proceeding. From these facts and opinions it follows that some islands were parts of a mainland within the lifetime of the existing species of animals and plants.

There are, however, indications all round our coasts that some other causes than simple marine and atmospheric erosion and wear and tear, may have assisted in the separation of tracts of land by the sea, and, therefore, in the production of islands. At low spring-tides, after gales of wind have caused the waves and currents to sweep the shore pretty clear of sand and shingle, the remains of what are called "sunken forests" are frequently found. Stumps of trees of such kind as the oak, for instance, of great size, are seen more or less hidden in mud, and an excavation will show that the roots exist in their original position in the earth. The oaks grew there, but now this kind of tree does not flourish within the reach of the spray of the sea. Hence it is inferred that the land has sunk and the sea has invaded old forest tracts. The stumps have been preserved, and the rest of the tree has gone. It may, moreover, be suggested, and with much probability, that the incursion of the sea in those places was rapid, and that the land wore away and sunk at a greater rate than the forest land could become bare of its trees from the effects of a sea-side climate. Again, in many localities on the sea-coast there are raised beaches, or places where a relic of a former shore may be seen up the cliff side many feet—and scores of feet in some instances—above the level of the present shore and high-tide mark. The land has risen out of the sea, then, and the old coast-line and shore deposits have been all worn away, except the little relic. These evidences of the former sinkings and risings of the land may be seen in many places on the sea-side between mainlands and islands which are within sight, or nearly so; and this former instability of the land must have produced results ending in the rapid separation of the former continuous land into mainland and island. Of course, upward and downward movements of the shores would tend to the breaking up of the coast-line, and its easier and more rapid destruction by currents, tides, and waves.

There are some islands close to continents which have been mainly produced by movements in the crust of the earth. Thus the Island of Bombay, off the west coast of Hindostan, has resulted from the bodily sinking down of the coast-line seawards, along a line parallel with the former coast. The mainland there, is composed of hard rock called basalt, which was once cast forth as lava from the volcanoes of the age. This basalt is found in flows one over the other, and extends in the centre and west of the peninsula of Hindostan over 200,000 square miles. It was once 5,000 feet thick, and about 2,000 feet of it have been worn away from the top on the mainland. But a falling-in occurred along the western coast-line, and the very top of the basalt formation is seen on the outskirts and in the midst of Bombay. Falling down into the crust of the earth along what called a line of fault, the topmost part of the thick deposit came to be just above the level of the waves, and it has been preserved from the wear and tear which have gone on over the mainland. Worn away, however, much of the sunken part has been, but there is a relic of the past in the island, and evidently this subsiding or faulting has had much to do with the separation of it from the mainland. The wearing of the sea, and of the air, and rain, and streams, assisted by the movement of the current along coast-lines, has had much to do with the formation of some islands. Assisting these potent powers has been the action of rivers near their mouths. The out-rush of river water, accompanied by tidal scour, wears away the land at the river mouth very irregularly, and hence small and large islands are to be seen in the estuaries and mouths of some rivers which are really relics of formerly continuous mainland. Probably the formation of the Isle of Wight, and its separation from the mainland, was partly due to the gradual wear of the rivers which flowed southwards from this last, and northwards from the island. Denudation, the removal of its products, and the slight movements of upheaval

and subsidence on or about the coast-line, have produced, therefore, the greatest number of islands which are situated close to continents or to large tracts of land. On the other hand, many islands have been formed near coasts in the line of the outpour of rivers, in what are called deltas, by the accumulation of sediment brought down by the stream, century after century, and which has not been carried off to sea by the tide.

The great islands which are situated close to continents, or which are not too remote to appear never to have belonged to one great mass of land, on maps, are somewhat numerous. Amongst them must be included the following: Tierra del Fuego, at the southern point of South America, Vancouver Island and some others north of it on the west coast of America; the Japanese Islands and Sumatra, off the east coast of Asia; Tasmania (or Van Diemen's Land), to the south of Australia; Ceylon to the south of Hindostan; Madagascar, to the east of Africa; the British Islands; Sicily, Cyprus, Sardinia, and Corsica, and others in the Mediterranean; Newfoundland, off the east coast of North America; and Cuba, Jamaica, San Domingo, and Trinidad in the West Indies. The remarks already made will apply to these islands, for there is no doubt that they were once connected with the mainland nearest to them. The word "once" has a very wide signification so far as lapse of time is concerned, and it must be remembered that the physical geography of the present age was foreshadowed and prepared during not only the last geological age, but during several antecedent epochs. If the proof of the former connection of certain islands with the mainland were to depend on perfect similarity of the animals and plants of both localities alone, the evidence would fail in some instances, but the geologist will be able to show in those cases that the construction of the surface of the earth was the same then in the island and on the continent, but possibly so long ago that the plants and animals have not much now in common, and that still there can be no doubt about the former continuity of land.

This can be understood by examining the trend, direction, and geology of the mountain systems of the continent and their relation to those of the islands. Geographical science has long since exploded the idea that the great mountains of the globe are in the centre of continents, and has shown that many are in parallel chains more or less close to the great oceans. These chains are broken by cross ranges, are often not continuous for great distances, and the valleys separating them are of all breadths, and are also parallel more or less with the sea-coast. It must not be forgotten, however, that the youngest mountains of the great land-mass of Europe and Asia are an exception to the general position, for they run across the continent, remote from the great seas; but nevertheless their chains present much parallelism. Now, omitting these last from the argument, it is perfectly evident that some of the islands near continents once formed part of the great land-mass because they contain mountains parallel to those on the mainland, and of the same geological formations and age. In the island, as a general rule, the highest mountain chain is central, or it may be made up entirely of mountains standing in deep water.

Looking at the instances mentioned, there is no difficulty in believing that Tasmania once formed part of the Australian alpine coast system, or that Madagascar was once part of an African coast-line. The same ancient condition may be extended to the islands on the north-west coast of Africa. The separation has been due partly to wear and tear, but mostly to irregular upheaval and subsidence. To estimate the amount of wear and tear and ruin of coast-lines, it is necessary to remember that many great rivers run right through the course of mountain ranges, and that they once flowed at a higher level inland, and wore their valleys down simultaneously with the erosion and widening of the channel through the hills to the sea. The action of the sea and tide on most coasts is less rapid than that of the running waters and scour of rivers in wearing down gorges into the sea. Isolation of a part of a coast-range can take place by the sea breaking the continuity of river-valleys which run parallel with the coast-range. It is evident that the sea does not erode its bed at any great depth under ordinary circumstances, and that its floor accumulates rather than loses. But currents and strong tides assist the erosion of the sea, and probably render it a wearing agent at greater depths than may be imagined. The moderate depth of water which often exists between some islands and continental tracts seems to be accounted for by the eroding action of the sea alone. Marine erosion, however, has produced only a part of most of the straits between discontinuous land; the rest has been due to tidal movement and to the previous condition of the valley which once separated the coast-ranges, the outer of which has become an island, and to movements in the crust of the globe.

Common sense might lead to the belief that the more distant island was invariably the oldest in relation to the neighbouring continent; and there is much truth in the theory. Thus in Asia, some of the great islands of the Indian Ocean bear a remarkable relation in distance and in their mountain continuation with the mainland. There is a range of mountains running from north to south, and apparently terminating in an easterly bend in the long

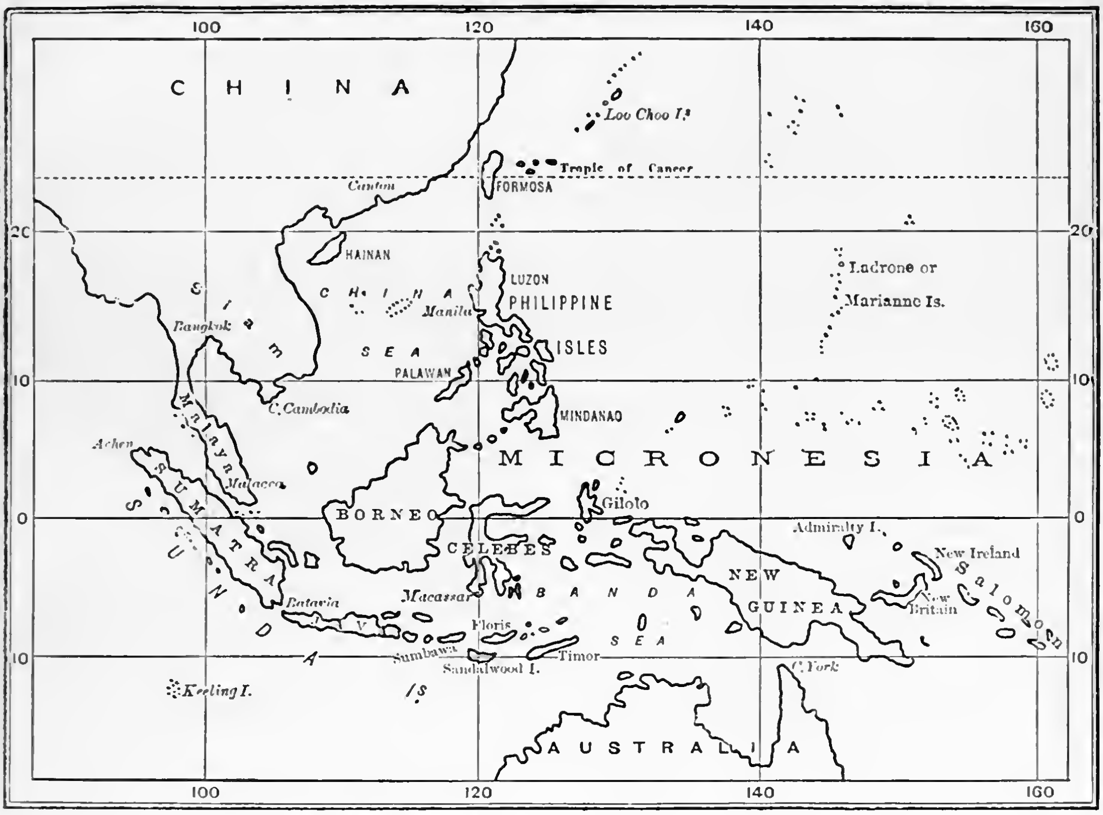

Fig. 1.—Map of the Malay Peninsula and adjacent Islands.

peninsula of Malacca. To the west of this range is a smaller one, passing from the eastern Himalayas southwards, in the district west of the Irrawady River, to the coast; and to the east, separated by the valley of Siam, is the chain of hills which, parallel with the others, limits Camboia. These three parallel ranges are stopped, as it were, by the sea; but not so in the eye of the geologist. For the first mentioned can be traced in a line of islands, or submerged mountain tops, from Singapore to Borneo, off the east coast of Sumatra; the second is recognised in the Andaman Islands, the Nicobar Islands, &c., and in the long central mountain ranges of the islands of Sumatra and Java (Fig. 1).

The third, or eastern range, does not appear to have a continuation; for the other great partly submerged mountain masses, and now known as islands—such as Formosa and the Philippines—belong to a cut-off coast-line. Sumatra and Java are separated but for a few miles from the Malay peninsula, and therefore it may be assumed that the former continuity dates back for no very great lapse of time. Now look at Eastern Africa, and there, separated by 300 miles, is the great island of Madagascar, whose mountain system is clearly a part of an old African land mass. It is credible that Madagascar has been separated from Africa longer than the other islands have been separated from Asia.

The former connection of all these islands with their nearest mainland may be inferred, on the principle already alluded to in this paper. That is to say, there being animals and plants of the same kinds on the continent and on the island, it is believed that they once lived on the land where there is now the separating sea. A very slight alteration in the north of the peninsula of Malacca would make it

into an island; and its plants and animals—the same in species as those of the neighbouring part of Asia—would be cut off from their fellows. The Germans call these peninsulas "half-islands," and a very good term it is, for it expresses much besides the simple geographical fact. Now the islands of Sumatra and Java clearly once formed a part of a "half-island," and their plants and animals were separated when the sea came in on the land, as it was worn or sunk at the present straits. The depth of the intervening water, which, if occupied by land, would connect these great islands and the mainland, is about 300 feet only; nevertheless, it is a barrier which prevents the great and small land animals from passing over. The Indian elephant, so common in Hindostan and in the countries to the East, is found in Sumatra; and a rhinoceros found in Sumatra is of the same kind as one which lives in Bengal. In the next island, Java, the rhinoceros is found, and it is of the same kind as that of the Malay peninsula; there is also a wild ox in the island, which is of the same kind as one which is found on the Asiatic continent. Again, an ape called the siamang, which can only live in the forest up in the trees, is common to the Malay peninsula and Sumatra. Another, the "wow-wow" gibbon, leading a similar life to the siamang, is found on the mainland and in Java. The vegetation of the islands is that of the mainland close by. All this leads to the belief that the separation of these great so-called continental islands took place from the mainland not so very long ago, and that it occurred during the lifetime of the kinds of elephants, rhinocerotidæ, gibbons, &c.; that is to say, since the present species have existed, and not before. Java is farther off the mainland than Sumatra, and it is found that about one-half of the larger animals of one island are found in the other, but the rest are not. Besides the creatures whose kinds were in existence when Sumatra and Java were one land, there are others, many of which, probably, have no relation to the former geographical continuity. These may be called peculiar. Long-armed apes of the genus Gibbon are found in the forests of many of the small islands to the east of Sumatra and Java, which are the partly submerged continuations of the north and south mainland mountain chains, and they are all forest monkeys. Hence these islands may be regarded as having once formed a part of a forest land continuous with the continent during the lifetime of the species of the monkeys. Still farther to the east is the great island of Borneo, forming now part of the parallel off-cutting of the continent of Asia, and once on a time a part of the same great country as the other islands. The wow-wow gibbon is found in Borneo as well as in Java; and probably at least one-third or one-half of their other animals are of the same kind. Again, the elephant and tapir of Borneo are of the same kind as those of the continent close by. All this proves that these islands and the mainland have been one at some time during the lifetime of the elephant, tapir, and gibbons; and the great number of species which are common to all these now separated districts, indicates that the age when they were divided is not very remote in the past. But the peculiar kinds of animals in the islands just noticed must have been introduced by accident or by birth since the islands were. These facts place the date of the separation a little remotely, and connect it with the end of the last geological age.

Take Ceylon as the next example. It is close to the southern end of Hindostan, and its mountains are of the same geological age as those of the east and centre of that part of India. There are elephants in the island of the same kind as those of the mainland, and some monkeys are the same, and others differ. The assemblage of animals and plants of the two neighbouring regions is so similar that there can be no doubt that the age of their separation is comparatively late in the world's history.

Distant Madagascar, however, tells a different story when its position and natural history are examined. It is a large island, with rather complicated mountain systems, and might be considered a little continent, were it not surrounded by sea, and close to land somewhat resembling it in its hills and their component layers. The sea is 300 miles wide which parts it from Africa; it is deep, and there is a strong current. If the island and Africa were ever united, it must have taken ages to have worn out such a space as the Mozambique channel between the two. The animals on the African coast and inland, such as the elephant, hippopotamus, giraffe, rhinoceros, and the great and small monkeys, are not found in Madagascar. There is not an animal which can neither fly nor swim which is common to the separated districts. Madagascar has a host of animals which are called lemurs—furry, active, four-handed creatures, usually with long tails (Fig. 2). None of the Madagascar kinds are found on the mainland. The mainland lemurs belong to genera which are different to those

of Madagascar. It is an interesting fact that a small or pigmy hippopotamus appears to have lived in Madagascar in the ancient time, for its bones have been found there included in late geological deposits. The pigmy hippopotamus lived far back in time, for its remains have been found in the islands of Malta and Crete, and in the Morea. It resembled greatly the small hippopotamus which now lives in Liberia, in Africa, and probably was the same kind. Moreover, there are some small islands between Africa and Madagascar, some of which are remote from the island, and others which are quite close, and these have the peculiar Madagascar lemurs on them.

From all these considerations it may be gleaned that Madagascar once formed a part of Eastern Africa; and that during a long lapse of time the 300 miles of deep sea have been got out of the land by current movements, by atmospheric wreckage, and by crust movements. So long ago was the separation, that it was before the world of monkeys enlivened the African forests, and before the great animals of the continent lived, the pigmy hippopotamus being the exception. All this indicates a great lapse of time, and a much greater one than that which occurred in the instance of the islands of Sumatra, Java, and Borneo in relation to Asia.

Fig. 2.—Lemurs of Madagascar.

TEETH.

By Dr. Andrew Wilson, F.R.S.E.

No structures of the human body are more familiar to ordinary observation than the teeth. In lower life, the teeth are equally well known and readily distinguished, even amidst variations in form, size, and appearance—variations that are often of considerable extent. Common as these organs are, however, their structure is a matter concerning which only students of natural science possess definite information; and the true nature of teeth, and their relationship to the other tissues by which they are surrounded, form subjects all unknown save to the learned few. Nor may the teeth interest us in their natural history alone. Among the many misfortunes to which humanity is liable, not the least serious and annoying are those evils which beset our teeth. And if the metaphysical doctrine that an analysis and understanding of our pains and sorrows be a proceeding tantamount to their mitigation and relief, a study of the natural history of the teeth may prove perchance to ameliorate, in a philosophical sense, some of the pains of man's estate.

The true nature of the teeth may form a fit subject for preliminary remark. Were the ordinary reader asked amidst which structures of the body he would classify the teeth, his natural reply would likely bear that the teeth belong to the skeletal portion of the body, and are allied to the bones in their nature. Such a remark would further seem to be fully borne out and supported by the superficial consideration of the teeth themselves. They are hard, dense, bony structures, bearing outwardly the closest possible resemblance to bones. They are, moreover, firmly fixed, in man and his nearest relations, in cavities or sockets excavated in the jawbones, and are thus placed in very intimate connection with bony structures. Plain as would seem the inference to be deduced from the foregoing fact —namely, that teeth are simply modified bones— the physiologist finds good and sufficient reasons for fully denying the apparent connection which might be regarded as existing between the skeleton and the teeth. The latter, he maintains, are not parts of the bony framework. In a true or natural classification of the bodily belongings, the teeth would be placed in quite a different section from the bones; and it is doubtful if any relationship, other than a superficial resemblance in chemical composition, can be shown to exist between bones and teeth. Let us try to ascertain the grounds for the physiologist's separation of these two structures; and in so doing we may glean some important information concerning the manner in which the true relationships of the structures of living beings are discovered.

In the endeavour to trace the nature of some of the existing features of society, such as its marriage-customs, or any of the institutions which mark the social life of our age, the investigator has recourse to antiquarian lore, and to the primitive history of our race. Therein he tries to discover the first beginnings of the habit in question, and if his search be successful, he will be able to trace the growth of the custom, and the history of the innovations which have suited or adapted it to the gradual advance of mankind. What is true of an investigation into man's personal history, and into that of his customs and habits, is equally true of the method whereby we arrive at the history of the

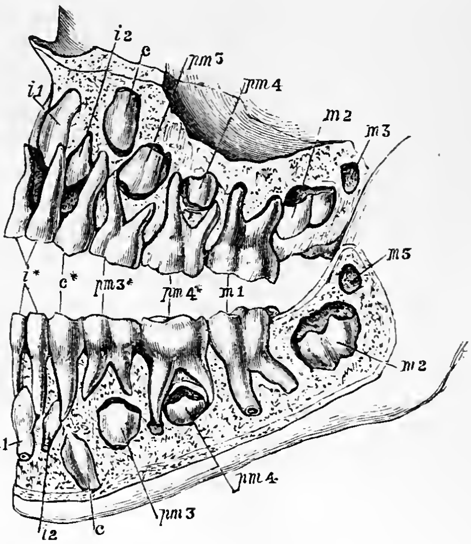

Fig. 1.—Teeth of Man, showing the Milk and Permanent Sets. (*After Owen.*)

(i^*, c^*, pm^{3*}, pm^{4*}) the Temporary Incisors, Canines, and Molars; (i^1, i^2, c, pm^3, pm^4, m^1, m^2, m^3) the Permanent Teeth succeeding the Milk Set.

structures of which his frame is built up. In either case, the subject under our investigation does not explain itself by its present aspect. We must travel back, in either case, to the beginning, and try to trace through *development* the true nature of the subject or structure under consideration.

Apply these remarks to the investigation of the teeth and their nature, and we shall speedily

find reasons for the separation of the teeth and bones. Suppose we watch the development of a tooth, we may find that its lines are laid down, so to speak, in a very different manner from that in which the bones are fashioned. Man and higher animals, as most readers are aware, possess two layers in the skin. The outer layer, as we know from our experience of ordinary life, is devoid of blood-vessels, and destitute of nerves. This outside layer is the *epidermis.** Beneath the epidermis we find the under skin, well supplied with nerves and blood-vessels, and known as the *dermis.*† This under layer of the skin is the more important of the two, since it is by means of its nerves that we feel, and through its "sweat-glands" that we get rid of a large proportion of the waste matters of our bodies. But these two layers of the skin, viewed altogether apart from these functions, also serve to form and develop certain *hard parts,* which come in due time to assume a permanent place in the structure of the body. Thus, for instance, the nails are formed by the *epidermis*: and hairs as well as feathers are no less typical developments of this outer skin-layer. The *callosities,* or hard patches or knobs, we see on the inner aspect of a horse's legs, or on the camel's breast, and horns themselves, may be also regarded as typical belongings of the outer skin. Indeed, the well-known "horn" borne on the nose of the rhinoceros, in its essential nature, is but a bundle of closely-packed and somewhat altered hairs.

The *dermis* or under skin also devotes part of its vital energy towards the formation of hard structures. Thus even within the limits of the great class (*Mammalia*) including man as its highest representative, the under skin presents us with evidences of its power in forming hard structures in the bony plates which, like a veritable coat of flexible armour, invest the armadillos of South America. But the under layer of the skin also possesses a more special interest for us when we discover that it is to this layer that we are indebted for our teeth, and that teeth in reality must be classified with the skin and its products in a true arrangement of the body and its parts. At the margin of the lips, the outer layer of the skin merges into the delicate structure seen in the lips themselves; and this latter layer in its turn merges into the still more delicate layer which we familiarly term the "gum." The "gum" is in truth simply an altered under-skin, and it is to the gum that we must look for the explanation of the formation of a tooth.

* Sometimes called the *ecteron.* † Or *enderon.*

The beginnings of tooth-formation take place at a very early period in the life-history of man and his animal neighbours, and the first traces of this work result in the production of a semicircular groove running round the upper jaw. This is the *primitive dental groove* of physiologists. In

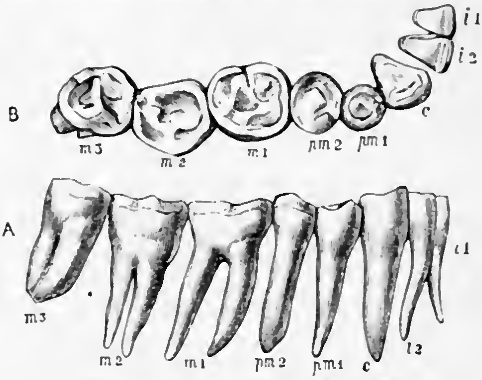

Fig. 2.—Teeth of Lower Jaw of Man.
(A) Side View; (B) Grinding Surface. (References as in Fig. 1.)

the floor of this groove appear a number of little projections or *papillæ,* each of which may be regarded as a veritable mould upon which a tooth is formed. The dental groove next becomes contracted; its edges tend to grow together, so as to inclose the little papillæ; and by a further development of the groove, each papillæ becomes inclosed in a little chamber or compartment of its own, named a *follicle.* It may be well to remark at the present stage of our inquiries, that the follicles are simply the representatives of the future "sockets" in which the true teeth will be duly and securely lodged. Inclosed within their compartments or follicles, the little papillæ begin to grow rapidly, and to assume each the form of a tooth. The upper part of each papilla has a little cap, which forms the *enamel* of the future tooth; whilst the substance of the papilla itself is devoted to the formation of the *dentine* or ivory, of which the great bulk of a tooth is composed. Ultimately the great bulk of the papilla will become the *pulp* of the tooth; and as soon as the proper period arrives, the gum will give way through the pressure of the tooth upon it, and the tooth, making its entrance into its proper sphere of action, is said to be "cut." Thus the study of the development of a tooth teaches us the following important facts: firstly, that teeth belong to the skin-structures, and are near relations of the hairs and nails; secondly, that each tooth is formed from a little projection called a *papilla,* formed in a groove, which ultimately becomes divided into follicles or sacs; thirdly, that the papilla, becoming

hardened through the formation of limy matter, forms the tooth, the central substance of the papilla remaining soft and constituting the tooth-pulp; and fourthly, that when the tooth emerges from its sac it is said to be "cut"—the follicle or sac forming the familiar "socket" of the tooth.

Thus much for the development of a tooth and what it teaches. The process just described refers to the *first, "milk," or temporary set* of teeth which man and his neighbours are known to possess. A second or *permanent* set appears in due course; the second teeth being developed in little pockets, which are given off from the follicles or sacs of the first teeth. In the bottom of each of these secondary sacs, a new tooth grows from a papilla, as in the previous case, and as the second teeth grow they press like rude neighbours upon the roots of their predecessors. This pressure causes the decay or absorption of the roots of the milk-teeth, which in the natural order of things fall out, and are replaced by the second set. Thus we learn something, through these latter facts, about the *succession of the teeth.*

Most quadrupeds resemble man in that they possess two sets of teeth; but those whales which possess teeth, the sloths, and some other quadrupeds, have but one set. Nor must we neglect to remark, in passing on, some rather interesting, not to say strange, peculiarities which mark the succession of the teeth in some animals. Thus the guinea-pigs actually shed their milk or first teeth before they are born. Still more curious is the case of the whalebone whales. In their adult state these animals have no teeth, but the teeth are actually developed in the gums, and absorbed before birth. So also with the upper front teeth of ruminants, or animals which, like sheep, oxen, &c., "chew the cud." These front teeth are duly formed and developed, but they do not cut the gum, and wholly disappear before the animals are born. "What," asks Mr. Darwin, in speaking of this subject, "can be more curious than the presence of teeth in fœtal whales, which when grown up have not a tooth in their heads; or the teeth which never cut through the gums in the upper jaws of unborn calves?" The only explanation which has been tendered of such anomalous and apparently useless organs, has been to assume that they are the results of "the law of inheritance," and exist as the modified remnants of teeth which in the "remote ancestors" of the whales and calves attained a large and typical development. But this is a mere hypothesis, and one which we need not discuss here.

Turning to consider man's teeth as to their number, we find him to possess thirty-two teeth in all: the sixteen teeth of the upper jaw presenting a similar form and arrangement to those of the lower jaw. Man's teeth form an unbroken series in each jaw—a character almost peculiarly human, since only one living animal, a little lemur (*Tarsius*) has the teeth so arranged (Fig. 3); an extinct hoofed quadruped, the *Anoplotherium,* also sharing this peculiarity. Man possesses only ten teeth in each jaw in his milk set; and this remark leads us to ask what becomes of the additional twelve teeth his permanent set contains? To answer this question, we may briefly glance at the varieties of teeth found in the category of human possessions (Figs. 1 and 2). Thus four front teeth exist in each jaw. These are *incisors,* or nippers. Next to those, one on each side, lie the teeth so pointed and prominent in the dog, hence named *canines,* or "dog-teeth." Then succeed two teeth on each side, with two *cusps* or points on each crown. These are the *bicuspids,* or premolars. Lastly come the *molars,* "grinders," or back teeth, with broad crowns, and which exist to the number of three on each side of each jaw.

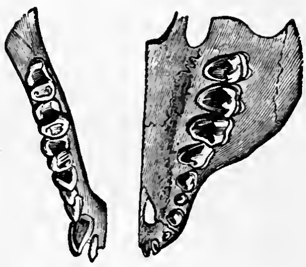

Fig. 3.—Teeth of Tarsius.

We may denote the number of teeth in any animal by a very simple arrangement of letters and figures, named a "dental formula." Thus we might indicate man's permanent tooth-arrangement or "dentition" by the following symbols, which are by no means so formidable as at first glance they may seem:—

$$\frac{\overset{m.}{3}\ \ \overset{pm.}{2}\ \ \overset{c.}{1}\ \ \overset{i.}{2}\ \Big|\ \overset{i.}{2}\ \ \overset{c.}{1}\ \ \overset{pm.}{2}\ \ \overset{m.}{3}}{3\ \ 2\ \ 1\ \ 2\ \Big|\ 2\ \ 1\ \ 2\ \ 3} = 32$$

The figures above the horizontal line indicate the teeth in the upper jaw; the figures below the line referring to the teeth of the under jaw. The vertical line divides the jaws into two equal halves—and this for the reason that we might require in some animals to note the occurrence of teeth in one half of the jaw that are absent in the other half. To render the construction of a dental formula clearer, we may select, as an additional example, that of the sheep (Fig. 4). This animal wants upper incisors and canine teeth, but possesses six lower incisors and two lower canines; the premolars and molars each existing to the number of six in each

jaw. The arrangement of teeth in the sheep might be thus expressed :—

m.	pm.	c.	i.	i	c.	pm.	m.	
3	3	0	0	0	0	3	3	= 32
3	3	1	3	3	1	3	3	

Returning to the subject of man's dentition, we find that from the twenty teeth he possesses as his milk set, the molars or grinders are excluded. When these latter teeth appear they do so but once in his lifetime, namely, in the permanent set, and

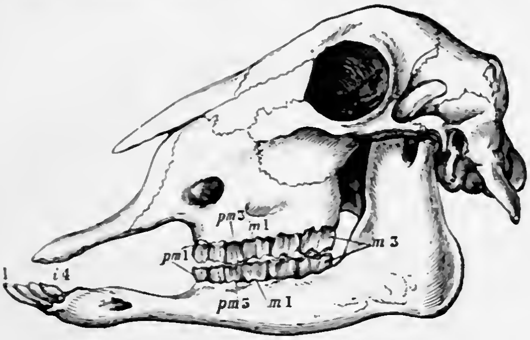

Fig. 4.—Skull of Sheep, showing Dentition.

are therefore not preceded by milk-teeth. The dental formula for man's milk set therefore runs :—

m.	pm.	c.	i.	i.	c.	pm.	m.	
0	2	1	2	2	1	2	0	= 20
0	2	1	2	2	1	2	0	

Fig. 5.—Growth of Tooth of Crocodile.

(a) Tooth fully developed; (b) Tooth nearly developed to succeed a; (c) Germ of Third Tooth which in due time will succeed and replace b.

Man's teeth are by no means numerous when compared with the numbers represented in some of his nearest allies, as well as with those developed in many lower forms of life. Some dolphins exist in which over 200 teeth are developed; whilst some armadillos must certainly be regarded as being well provided in the matter of dental apparatus in the possession of ninety teeth. On the side of limitation in numbers may be mentioned that curious dolphin-like animal the narwhal, or "sea-unicorn"—of whose dental peculiarities more anon—in which but two teeth are found.

When man loses any of his second teeth, he knows that all hope of replacement of the missing member by Nature is useless, and he has therefore to submit himself to the tender mercies of the dentist in order to supply the gaps in the necessary furnishings of his mouth. Infinitely superior, in respect of the arrangements for the renewal of lost teeth, are the faculties of many lower forms of life.

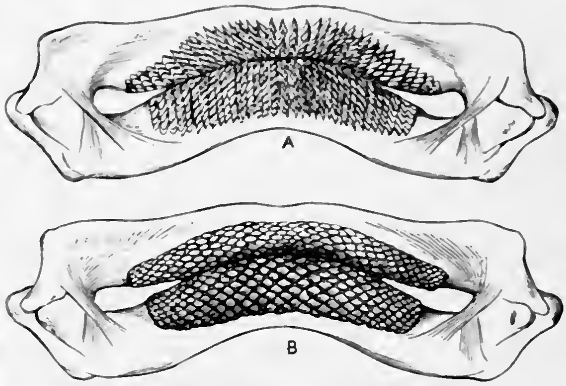

Fig. 6.—Jaws of Male (A) and Female (B) Skate.

Think of the crocodiles (Fig. 5), which are so lavishly provided for by Nature in the matter of teeth that whilst one tooth is in use, not one alone, but actually two,—new teeth may be in process of formation below the still useful member, the teeth succeeding each other vertically in these animals. Or consider the arrangement of the teeth in many members of the class of fishes. Glance into the mouth of a pike or perch, and you will speedily discover the teeth to

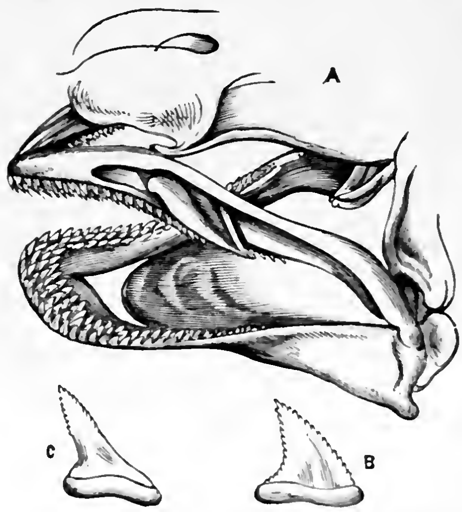

Fig. 7.—Jaws (A) of Shark; (B) Tooth of Upper Jaw; (C) Tooth of Lower Jaw.

be so numerous that Nature has crowded them not upon the jaws only, but upon tongue, palate, floor, and sides of the mouth, and upon the gill-arches, and back of the throat. Or look at the jaws of a

shark (Fig. 7), or a skate (Fig. 6), or ray, in which series after series of new teeth is developed, one behind the other, ready to be pushed forward and to occupy the place of the teeth at present in use. An Australian shark (*Cestracion*), presents us with a perfect pavement-like arrangement of teeth in its jaws; and in the rays, the teeth remind one of nothing so much, in their profusion and regularity, as the paving-stones in a street, or in some cases like the arrangement of mosaic work. In these latter cases set after set of teeth may be developed, in striking contrast to the meagre provision made by Nature in the matter of teeth in her highest flight of development as represented in man's estate.

The chief remaining points in the history of the teeth may be included under the heads *tooth-structure*, and *peculiarities in tooth-development.* When a tooth is cut in two longwise, it is found to be hollow in its interior. This hollow in the living tooth is occupied by the delicate *tooth-pulp* (Fig. 8, A, *p*), which consists, among other things, of blood-vessels and nerves, entering the cavity of the tooth at its roots. The tooth-pulp represents the papilla, upon and from which, as we have already seen, the tooth was at first formed. The great bulk of a tooth consists of *dentine* or *ivory* (Fig. 8, *d*), which, resembling bone in outward appearance, differs markedly therefrom in its essential structure. A transverse microscopic section, or thin slice of bone cut across, shows us that it consists of rings of bony matter surrounding the minute *Haversian canals* (Fig. 9, B, *a a*) in which the blood-vessels of the bone are contained. A section of dentine or ivory (Fig. 9, A, *b*) similarly examined, shows that this substance consists of branching tubes which, in a living tooth, are filled with delicate extensions of the tooth-pulp. The *enamel* forms the second of the three elements in a tooth. This latter is the hardest substance of the animal tissues, and forms a delicate investing crust to the tooth as far as the root. The enamel is thickest on the crown, where the tooth is most subject to wear and tear. The *cement* (Fig. 9, A, *b*, *c*) of a tooth exists on the roots, and is thickest at the points of the fangs. This latter substance most nearly, of all the substances found in a tooth, resembles bone.

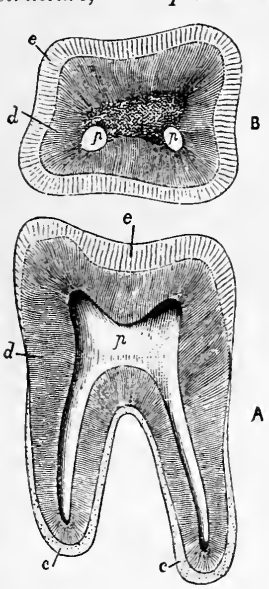

Fig. 8.—Longitudinal (A) and transverse (B) Section of Molar Tooth of Man.
(*c*) Cement; (*d*) Dentine; (*e*) Enamel; (*p*) Pulp-cavity.

No better illustration of the importance of correctly distinguishing between teeth and bone, could be given, than the case of certain fossil birds, which, in contradistinction to their living neighbours, possess teeth-like "processes" on their jaws. Part of the skull of such a bird was discovered in the London Clay of Sheppey, the jaws being provided with tooth-like structures. Under the microscope, however, the "teeth" of *Odontopteryx*—as the Sheppey fossil was named—were seen to be composed of bone, and to be therefore entirely different in nature from true teeth. Later on, and indeed quite recently, certain bird-remains, from the Cretaceous or Chalk Rocks of America, have been found to exhibit tooth-like processes of the jaws like *Odontopteryx.* When, however, the question of the true nature of the teeth of these American birds came to be raised, these latter structures were found to be true teeth in every respect. Their structure was that of true teeth, and they sprang, in one form at any rate, from distinct sockets. Thus the exact nature of a tooth as distinguished from bone is seen to be a highly important point in settling the status and relationship not merely of living forms, but of some of the more extraordinary relics of the life which existed in the æons of the past.

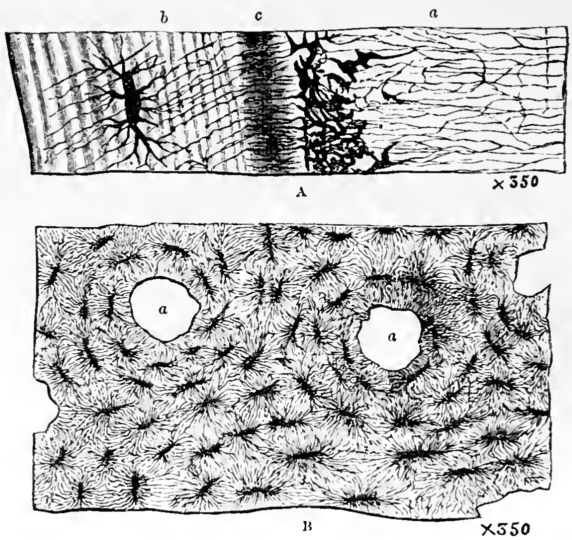

Fig. 9.—Dentine and Bone.
(A) Vertical Section of Dentine and Cement from Incisor Tooth of Man; (*a*) Dentine; (*b*, *c*) Outer and Inner Layers of Cement; (B) Transverse Section of Bone from *Humerus* of Man; (*a*, *a*) Haversian Canals.

Some teeth, such as those of sloths and armadillos, have no enamel. In the molar teeth of the elephants, on the contrary, we meet with a very complicated structure. In these animals a molar tooth exists as an elongated body, composed of plates of dentine capped by enamel, and separated by masses of cement. The patterns assumed by the dentine and enamel plates exhibit variations in the different species of elephants. Thus in the African species (Fig. 10) the teeth exhibit lozenge-shaped spaces, whilst the molars of the Indian species (Fig. 11) show a simple trans-

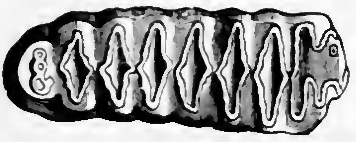

Fig. 10.—Molar Tooth of African Elephant.

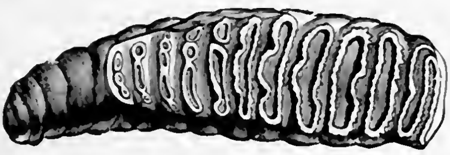

Fig. 11.—Molar Tooth of Indian Elephant.

verse or cross-barred arrangement, also witnessed in the teeth of the extinct mammoth. In the elephants we note a good example of the immense development of certain teeth—the upper incisors—to form "tusks." Such "tusks" spring from what are termed *permanent pulps*—that is, the roots of these teeth do not, as in man and most other animals, become sooner or later absorbed, but

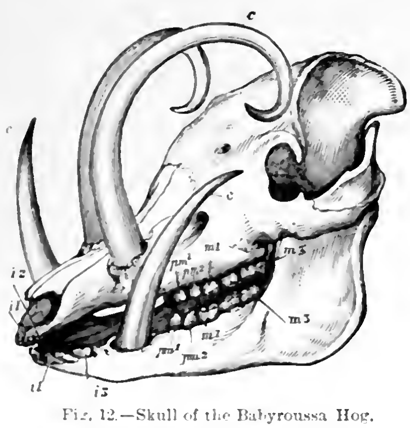

Fig. 12.—Skull of the Babyroussa Hog. (References as in Figs. 1, 2, 4.)

continue in a soft living condition, which permits of a continuous increase taking place. In the same way, the incisor teeth of such animals as rats, mice, rabbits, hares, squirrels, porcupines, beavers, &c. (named collectively *Rodents*), continue to grow throughout life, and thus to provide for the constant wear and tear to which these teeth are subjected in the act of gnawing. But in these animals we note another important and equally interesting provision of Nature for preventing too rapid wear of these prominent front teeth. The front part of each incisor tooth in the rodents consists of a thick layer of *enamel;* the hinder part of the tooth being composed of the softer *dentine*, or "ivory." It follows, therefore, from this arrangement of tooth-substance, that the ivory, or hinder part of the tooth, will wear faster than the enamel front, and the constant use of the tooth tends to keep a chisel-like edge thereupon, and thus provides for its continual sharpness.

Fig. 13.—Skull of the Narwhal. (a) The Developed Tooth; (b) the Undeveloped one.

Some marked peculiarities of teeth result in rodent animals, from disuse of these long incisors. When the incisors of one iaw in a rabbit, or hare, or other rodent, are accidentally broken, the opposing teeth of the lower jaw, being left unworn for a time, may grow rapidly, and extend well-nigh into a complete circle, preventing the closure of the mouth, and ultimately killing the animal. And an allied but natural state of what we may call tooth-deformity is found in the Babyroussa Hogs of the Eastern Archipelago, where the upper canine teeth grow upwards and backwards so as to resemble horns, the lower canines also attaining a large size (Fig. 12). The longest tooth in the world is that of the male narwhal (Fig. 13), which develops one tooth—the nature of which is doubtful—to a length of ten or more feet; this great tooth appearing as an ivory pole of twisted conformation. Sometimes two such teeth are developed, and occasionally the female narwhals

imitate their lords and masters in the development of a like formidable appendage.

Our space will not permit us to further descant on the peculiarities of tooth-structure. We may, however, mention one remarkable instance of modified teeth found in a class of animals—in which certain of the teeth are as a rule remarkably constructed to form poison-fangs—namely, the serpents. One little African snake, named *Rachiodon*, appears to subsist on eggs as its normal dietary. The puzzle of ordinary snake-existence with such epicurean tastes is obvious in the difficulty such an animal would encounter of obtaining the full benefit of its dainty fare. But Nature has overcome this difficulty in a sufficiently remarkable way. Certain processes of bony character project from the front of the spine and protrude into the throat; these processes being tipped with enamel. Although these processes are skin-formations, they seem to lie outside the category of ordinary teeth, from their peculiar position. Their function, however, is no less peculiar than their position. The eggs being swallowed whole, these throat-teeth duly fracture them in the course of their descent to the stomach, so that the snake in this way obtains the full benefit of its food, and contrives to procure the entire amount of its fragile diet.

The subject of the teeth and their modifications may be regarded as carrying its own lessons with it. One consideration, however, may be said to be plainly derivable from such a theme—namely, that the teeth very typically and beautifully illustrate at once the marvellous adaptation of animal forms to varied ways of life, and the wondrous fertility of contrivance which is characteristic of life at large.

HOW THE RIVER SEVERN CUT THROUGH WENLOCK EDGE.

By Charles Callaway, M.A., D.Sc. (Lond.), F.G.S.

WENLOCK EDGE is a lofty ridge of limestone running to the south-west through the heart of Shropshire. At Ironbridge, the river Severn cuts right through it, leaving a steep rampart of rock standing up on each side. How has this been done?

Are we to suppose that the river came rushing down from Plinlimmon, swollen into unusual volume by heavy rains, and that it burst through the great rock barrier as a cannon-ball breaks through a stone wall? Or shall we adopt a milder explanation, and suppose that the Severn flowed down gently against the ridge, and, by continual washing and wearing, gradually worked its way through, as a mouse nibbles through a cheese?

To both of these explanations there is a very strong objection. If the Severn had come down from the Welsh mountains against Wenlock Edge, it would at once have ceased to be a river. The water, dammed back by the barrier, would have spread out into a lake, and would have found an outlet in another direction. In that case, the water would probably have turned into the flat plane north of the Wrekin, and flowed across England to the German Ocean. We are then obliged to conclude that Wenlock Edge did not form a barrier to the flow of the river.

Sir Roderick Murchison suggested a way out of the difficulty. He contended that the mountain barrier split asunder, and gave passage to the river. In proof of this he points out that, just where the river enters the gorge, the limestone is displaced by a "fault." To this theory there are two objections. First: the fault was simply "a plane of separation," that is, a crack in the strata, with the rock on each side of the crack in actual contact. Second: the river has not taken advantage of the split, which is unopened to this day, but has cut through the edge in a different direction.

If, then, the river did not burst or eat its way through the present barrier, and if the barrier did not crack open for the passage of the waters, how can it be said that the Severn has cut its way through Wenlock Edge? I will here give a partial answer. The river existed before the mountain, and not only cut the gorge, but also helped to make the mountain. To explain this, we must go back to the very ancient times when neither the river nor the Edge existed.

In the epoch called the Silurian, the ocean rolled where now the angler fishes for salmon in the Severn, and where the Ironbridge labourer burns the limestone of Wenlock Edge. We are here concerned only with a sub-division of the Silurian epoch which takes its name from the very district under consideration. It is called the Wenlock period. At the bottom of the Wenlock sea, there first accumulated thick beds of calcareous mud, on

the surface of which crawled myriads of strange beings the very types of which have long since passed away; while the ancestors of the nautilus, with shells straightened out like the horn of a unicorn, swam in the ocean above, and were monarchs of all they surveyed. After a time, the supply of mud fell short, and the sea grew clearer. This allowed coral reefs to form. For ages, zoöphytes, the ancient representatives of our Madrepores and star-corals, were busy separating the carbonate of lime dissolved in the ocean, and building it up into their skeletons, which, by their accumulation, grew into solid reefs. The zoöphytes were aided by the stone-lilies. These were animals of exquisite beauty and grace. A slender stem, composed of flat rings of solid carbonate of lime, was rooted to the bottom of the sea, and supported a calyx or cup shaped like the flower of the lily, and carved on the outer surface as by the graver of a Cellini. Round the upper edge of the calyx was attached a circle of long jointed arms furnished with delicate fringes. The entire framework of this lily-like creature was constructed of plates, rings, and joints of solid stone; and, when the soft parts of the animal decayed, its imperishable skeleton helped to form great beds of solid rock. (Vol. I., Fig. 1.)

Thus we have a thick deposit of calcareous mud, the Wenlock Shale, overlaid by a band of more solid material, the Wenlock Limestone. The difference in the hardness of these two bands is the essential point to be remembered. The limestone was afterwards covered in by strata, which we will call Post-Wenlock.

The next stage in the process is the conversion of the Wenlock sea-bottom into dry land. This was brought about by gradual upheaval. The layers of rock composing the earth's crust were puckered into huge waves by a tremendous force pushing sideways. As the tops of the arches approached the sea-level a new power came into operation. This was the action of the waves of the ocean.

The operation of this agency may be seen in many parts of our coast-line at the present day. Waves beat at the base of the cliff like the ponderous hammers of Cyclopean giants. The waves act with greater effect by means of the pebbles and sand which they drive before them. In this way cliffs of the most solid rock are undermined, and masses above, being unsupported, fall down, and accumulate at the base. Then the restless waves commence upon the fallen heaps, dashing them together, breaking them to pieces, reducing them to pebbles, and grinding the pebbles up into sand and mud. Last of all, currents come and sweep away the sand and mud into the ocean, leaving the base of the cliff once more bare. The waves again set to work, and undermine a fresh portion of the precipice, and the grinding up process is repeated. In this way, the waves eat in upon the land, like a great horizontal saw working unceasingly at the same level, and the cliffs retreat before them. The waves have no more respect for the most solid and stately cliff than they had for the chair of Canute. If there were no counteracting force at work, they would gradually eat their way in upon the land until every atom of rock above the level of the sea was swept away, and the ocean would be universal.

Let us return to our arches of rock rising up to the surface of the ocean. The waves set to work upon the apex of each arch, and plane it off. As the land rises higher and higher, more and more of the arch is removed. The upheaving force and the waves are running a race. Upheaval is trying to gain upon the waves, so as to lift the land up above their reach; and the waves are eager to swallow up the land before upheaval can attain its object. We will suppose that upheaval wins the race, and produces dry land. That land-surface will be level, owing to the planing action of the waves during the emergence. Fig. 1, taken from a section exposed in a quarry near Skipton, shows how the beds of rock in the earth's crust are bent into waves, and how the ocean has planed off the arches to a level surface.

During the emergence of a portion of the earth's crust, the centre of the mass will evidently move upwards more rapidly than its circumference; so that the new land will be rather higher in the centre. Such a newly-formed land-surface, which slopes gently out towards the sea, is called a "plain of marine denudation." The flat plain of central Ireland is an example.

Let us now revert from our general principle to our special case. To prevent unnecessary complication, we will confine our attention to our three bands of rock, Wenlock shale, Wenlock limestone, and Post-Wenlock beds; and we will suppose that all formations above and below these groups are non-existent. Our series has been uplifted into an arch, planed off by the waves, and converted into a plain of marine denudation, with a gentle slope towards the south-east. Fig. 2 represents a part of this land-surface.

As soon as the land emerges from the waves, a new set of agencies begin to work upon it. The

principal of these forces are frost, rain, and carbonic acid. Rain-water falls upon the surface, and soaks into it, penetrating even the more solid rocks. Frost sets in, and the water in the rock congeals. But when the water freezes it expands, and splits the rock. Each particle of water lying between two particles of stone, by its expansion, acts as a little wedge, forcing the rock particles asunder. In this way, an exposed rock-surface, moistened from time to time by rain, gradually softens and decays, or peels off in flakes.

Frost having done its work, rain again resumes operations. Every shower washes down some of the decayed rock-surface, and the streams produced by the rain carry the sand or mud down into the river below.

The atmosphere contains a small quantity of carbonic-acid gas, and the rain falling down through the air, dissolves a small portion of the gas, and thus acquires its chemical properties. The only property of carbonic acid which we need notice here is its power of dissolving limestone. A stream of water passing through a crack in limestone will often dissolve the rock on each side to such an extent as to enlarge the crack into a cavern.

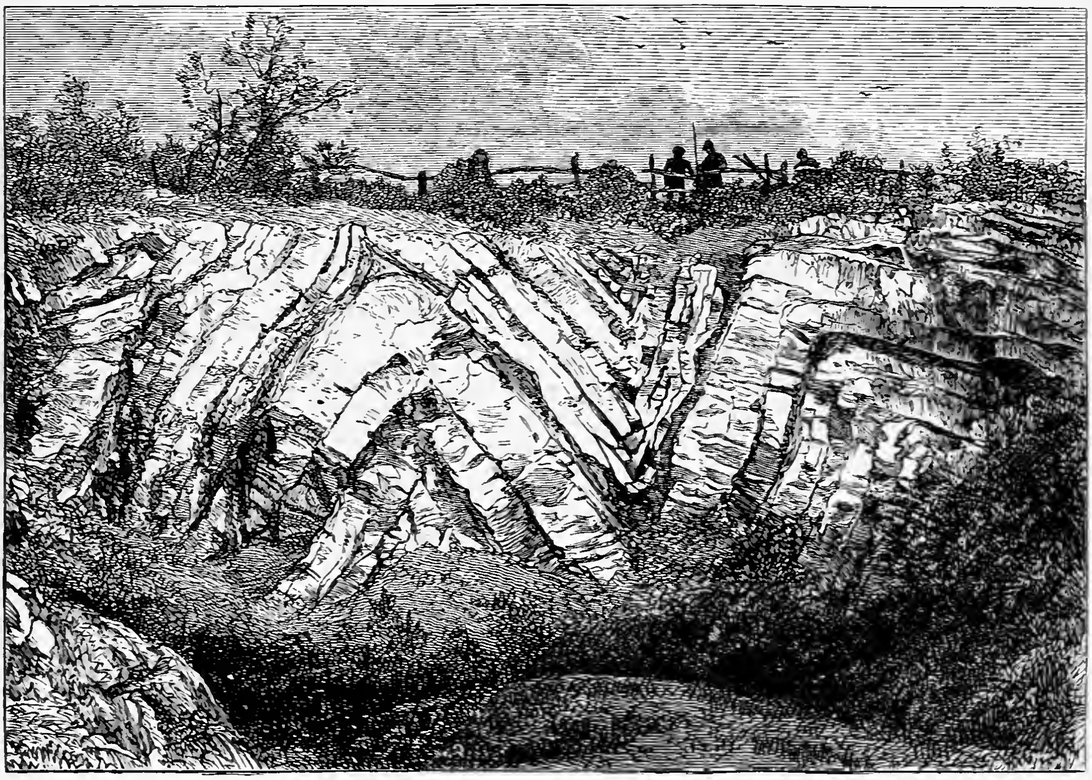

Fig. 1.—Contorted Limestone at Draughton, Near Skipton.

We can now introduce the river Severn. Rain falls upon the newly-emerged plane of marine denudation. If the plane were a perfectly smooth sloping surface, the rain would necessarily flow off in an even sheet. But billiard-table surfaces seldom occur in nature. The varying hardness of the material composing the plane will cause inequalities, even before a drop of rain falls upon the surface. Thus showers, accumulating on the land, will run off to the sea in some directions more readily than in others. Rain, falling on the higher ground in the centre of the emerging plane, flowed off towards the south-east and formed the Severn. The reader will imagine the river to be moving from B to A in Fig. 2.

But it is not to be supposed that a narrow, compact, deep stream was formed all at once. The primeval Severn was probably a chain of irregular sheets of water. In one place the water would spread out into a lake; in another it would be contracted into a broad, shallow stream. But this

would not last long. The motion of the water would wear away the surface over which it flowed. As the land rose higher and higher, the speed of the stream increased, and its excavating power increased in proportion. Thus, the ancient Severn gradually cut out a channel for itself, and an irregular, meandering chain of pools became a narrow, rapid river, confined within its own banks.

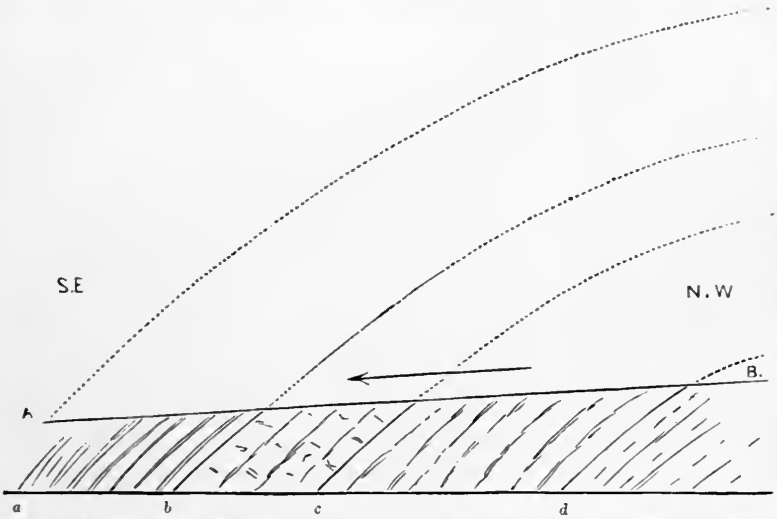

Fig. 2.—A B is the Plane of Marine Denudation. The Dotted Lines indicate the original Extension of the Beds forming one Side of an Arch. The Arrow shows the Direction of the River's Motion. (a to b) Post-Wenlock; (b to c) Wenlock Limestone; (c to d) Wenlock Shale.

This river-action is to be carefully distinguished from the action of the sea. The waves cut horizontally, like a horizontal saw, producing a level surface; but a river cuts downwards, like a vertical saw, causing inequalities in the surface.

But the primeval Severn was not a simple stream of water. It was a main trunk receiving smaller streams, called tributaries, and these tributaries, like the main current, cut down into the crust, and excavated channels. The excavating power of the river and its feeders was aided, in the manner described, by frost, rain, and carbonic acid. If the streams had acted alone, they would have cut regular trenches with vertical sides. These trench-like valleys are called cañons (Vol. I., p. 208). In countries where rain falls, the river-valleys assume an altogether different shape. While the stream at the bottom is cutting down deeper and deeper, frost and rain are wearing away the sides, so that the vertical wall gradually retreats backwards into a slope. If the walls of the valley are composed of soft material, such as clay, the slope will become very gentle, and the valley will be broad and open; but if the rock is hard the sides will be steeper. We must now come back again to the Severn.

Our river, flowing down towards the south-east, passes over the three distinct formations, soft Wenlock shale, hard Wenlock limestone, and soft Post-Wenlock rock. It eats its way down into all three indiscriminately. Its progress through the limestone is aided by the solvent power of carbonic acid, and by the direction in which the band is lying. It will be noticed that the dip is towards the south-east. If it had been towards the north-west, a very different effect would have been produced, and a waterfall might have been formed. But that does not concern us here.

Where the valley is excavated in the shale, the slopes down to the river are low and gentle; but as the Severn approaches the limestone, the valley closes in, and forms steep sides, due to the superior hardness of the limestone band. Thus the river, which has been winding through a plane, suddenly passes into a narrow gorge. There has been no cataclasm, or deluge, or fracture. The thing has been done by Nature in her ordinary gentle mood, without hurry, and without convulsion. Thus the river cut the gorge. It also helped to form the mountain.

We must go back again to the tributaries. Some of these fell into the Severn in its course through the Wenlock shale, others joined it after it had passed over the limestone. These tributaries excavated the softer rock both above and below the harder band. As the main stream cut *transversely across* the three zones, deepening its bed through all three indiscriminately, the branches, assisted by frost, carbonic acid, and rain, were

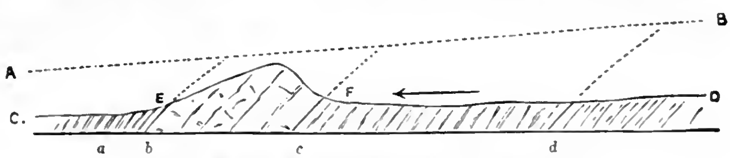

Fig. 3.—New Surface produced by Action of the River. (a to b) Post-Wenlock; (b to c) Wenlock Limestone; (c to d) Wenlock Shale.

hollowing out the shale in lines *parallel to* the three bands, leaving the limestone standing up as a ridge. Thus the Severn also helped to form the mountain. Fig. 3 shows the new surface produced by the action of the river.

A B is the old plane of marine denudation represented in Fig. 2. C D is the present surface of the country. The river has cut its way down from A B to C D, having removed all that portion of the land which is contained by the dotted lines. The Severn flowing in the direction of the arrow, passes over the shale, enters the limestone gorge at F, and emerges at E. Thus the river Severn cuts through Wenlock Edge.

Thus, also, the Avon at Bristol, the Shannon at Limerick, the Hudson of New York, have cut channels through opposing ridges. Thus, the Medway, the Mole, and the Wey breach the North Downs; and the Arun, the Adur, and the Ouse carve valleys out of the South Downs; and such is the usual manner in which rivers cut through mountain ranges.

MOLES AND MOLE-HILLS.

By Edward R. Alston, F.L.S., F.G.S., etc.

"Well said, old Mole! Canst work in the earth so fast?
A worthy pioneer!"—*Hamlet.*

A MOLE-HILL is such a familiar and commonplace object, that most people would hardly think it worthy of a second thought, unless, indeed, it marred the symmetry of some close-shaven lawn, in which case the mole-catcher would probably be called in to destroy the hapless constructor of the offending hillock. The naturalist, however, views it with very different eyes, seeing in it the handiwork of one of the most interesting of our native mammals, one whose habits and structure have long been the objects of careful study, and yet one whose economy has been widely misunderstood and misrepresented.

Many quadrupeds, as every one knows, are in the habit of constructing burrows in the earth, but the vast majority of them—such as foxes, rabbits, and prairie dogs—use their holes merely as retreats from danger, as sleeping-places, as nurseries for their young, or as storehouses in which to garner up provisions against winter. A very small minority, however, spend the greater part of their lives in tunnels and passages which they excavate beneath the surface, where they seek their food, carry on their courtships, and rear their young in utter darkness; and to these truly subterranean quadrupeds our attention will at present be confined. Most of them are rodents, or gnawing animals, which feed on the roots of plants; but the most typical and highly specialised are the insectivorous mammals which form the family of Moles, or in scientific language, the *Talpidæ*. These little animals feed almost entirely on earth-worms and on the burrowing grubs of various insects, and they are as remarkable for their voracious appetites as for their strong passions of love and hatred, and their untiring energy and vivacity. Consequently, it is necessary that they should be able to move through the earth with much greater ease and rapidity than suffices the sluggish vegetarian rodents, and accordingly their structure is wonderfully modified to give them the requisite powers. Let us inspect the machine before we consider the work which it produces.

With the external characters of the mole most people are familiar, thanks to the mole-catcher's habit of hanging the corpses of his victims on trees

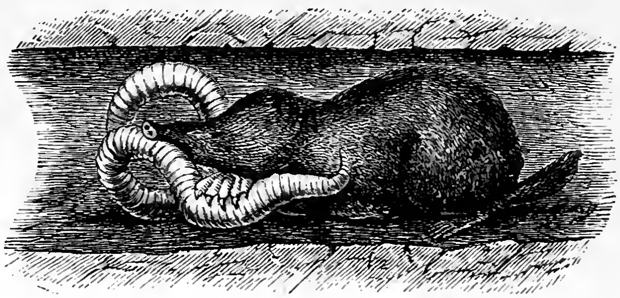

Fig. 1.—Mole, Feeding. (*From a Sketch from Nature.*)

and bushes. Its almost cylindrical body, its long, pointed snout (which is strengthened by a small bone), and its broad out-turned fore-paws, are evidently admirably fitted to enable it to force its way quickly through the most tenacious earth, while the smallness of its eyes and external ears, and the velvety closeness of its fur, serve to protect it from the annoyance which loose sandy soil might otherwise cause it. But to understand fully how

the mole can do its work, we must examine the bones of its fore-limbs and shoulders. These are of the shape shown in the figure. The shoulder-blade (the *scapula*, Fig. 2, *a*) is long and narrow, but strong, while the collar-bone (*clavicle*, *b*), is a thick disc, the shape of which has been well compared to

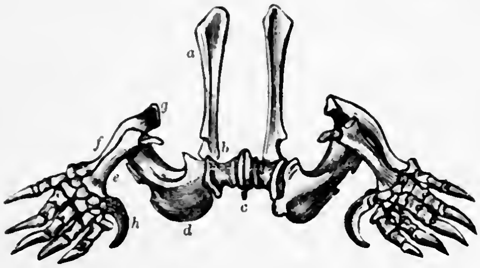

Fig. 2.—Bones of a Mole's Shoulder and Fore-limb. (*After De Blainville.*)

that of a fish's vertebra; it is only connected with the shoulder-blade by ligaments, but (at *c*) it articulates with the greatly-produced front part of the breast-bone (the *pre-sternum*). The upper arm-bone or *humerus* (*d*) is extremely short and stout, and is so covered with great ridges for the attachment of muscles that it appears to be quite deformed; besides the ordinary joint with the shoulder-blade it has a separate articulation with the collar-bone, an arrangement which adds enormously to the power of its lateral stroke in digging. The fore-arm bones (*radius* and *ulna*, *e*, *f*) are also short and strong, and the latter has a greatly-developed elbow-process or *olecranon* (*g*). The hand is expanded into a broad, powerful spade, the breadth of the palm being increased by a special additional bone (the radial sesamoid, or *os falciforme*, *h*), which runs along its curved inner edge. Imagine this framework clothed with muscles of corresponding power, and armed with short strong claws, and you have a digging-machine most excellently adapted to enable the animal to pursue its subterranean prey with ease and rapidity. How it is used may be seen by any one who can contrive to catch a live mole, and to place it uninjured on the ground. Immediately it plunges its sharp snout into the earth, two or three powerful side-strokes of the fore-paws suffice to bury most of its body, the hind-feet give a comical kick in the air, and the whole creature disappears from view with a rapidity which is absolutely startling.

The small heaps of loose soil which we term mole-hills do not mark the residence or home of the animal, being merely composed of the material which it excavates in the formation of its temporary passages in pursuit of its prey. Its true home, or "fortress," as it has been termed, is placed at some distance from its usual hunting-grounds, with which it communicates by one or more permanent passages or "high roads," and consists of a spherical chamber, usually about five or six inches in diameter. In almost every book on natural history will be found plans, elevations, and descriptions of a mole's fortress, representing it as being constructed on a beautifully symmetrical design. In these books the central chamber (Fig. 3, *a*) communicates by three ascending passages with a circular corridor at a somewhat higher level (*b*), which in turn has five equi-distant descending tunnels leading to a lower concentric circular gallery of a wider radius (*c*), from which the outer roads or passages diverge, while an additional dipping shaft (*d*) leads from the bottom of the chamber and opens into the principal avenue. Nothing can be more beautiful, but unfortunately we find on investigation that the whole story has been copied, along with the illus-

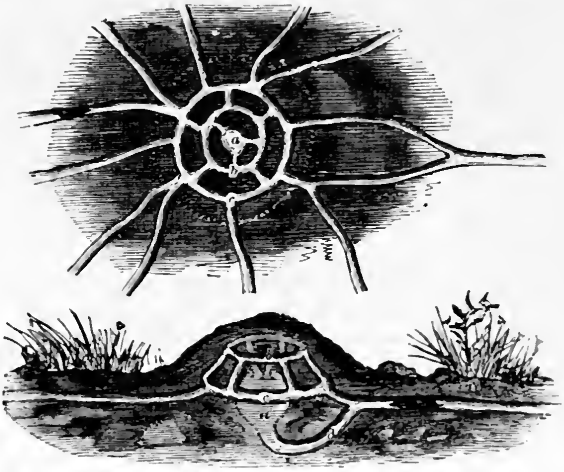

Fig. 3.—Conventional Plan and Elevation of a Mole's "Fortress," as given in Books.

trations, by one writer from another, without any one having taken the trouble to verify it. It appears to have originated with Le Court, a French gentleman who retired to the country during the troubles of the first Revolution, and devoted the rest of his life to the study of the mole. His observations, many of them valuable, but some of them certainly erroneous, were published by De Vaux, and by the elder Geoffroy St. Hilaire, and subsequent zoologists appear to have accepted all his statements without any test of their accuracy. Whether Le Court figured the habitation of some mole of genius—some talpine Euclid or Vauban—or whether (as appears

to us more likely) his national love of symmetry and beauty led him to improve on Nature, there is no doubt that ordinary moles content themselves with much simpler dwellings. Those which we have had an opportunity of examining have consisted of a large hillock, perhaps three feet in diameter, and about half as high, overgrown with herbage and sheltered among stones, fences, or roots of trees. The nest, or chamber, is placed near the middle of the hillock, just below the level of the surrounding ground, and has various passages branching irregularly from it. These are usually connected with one another at no great distance from the chamber by cross-runs which, sometimes, but not always, assume a more or less circular form; but we have never seen anything approaching to the regular system of concentric circles shown in the conventional plans. We are indebted for the sketch of the section of a mole's fortress from which the

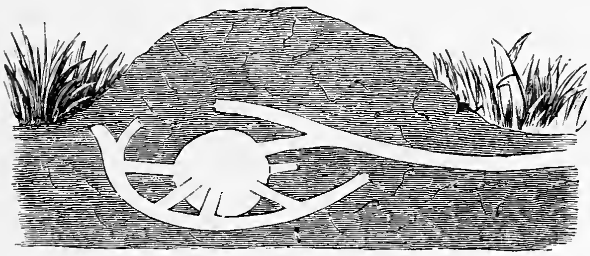

Fig. 4.—Section of a Mole's "Fortress." *(From a Sketch from Nature.)*

accompanying figure is drawn to the courtesy of Mr. F. Norgate, who has paid much attention to these animals, and has lately published some interesting notes on their habits.*

The "high roads," or avenues, to which we have already alluded as forming the communication between the citadel and the hunting-grounds, are permanent ways, the walls and floors of which are beaten hard by the constant passage of the animal. From the high road diverge the "alleys" or temporary tunnels which the mole forms in pursuit of its prey, and it is over these that our well-known "mole-hills" are usually made. In forming its permanent passages the mole seems to avoid throwing up hillocks, working slowly, and getting rid of the soil by compressing and beating it down rather than by bringing it above ground. But when engaged in the chase the animal comes to the surface every now and then and throws out the superfluous earth; and the same is the case in the formation of the superficial runs which the male makes in spring in pursuit of the female.

* "Transactions of the Norfolk and Norwich Naturalist's Society," 1878.

We have already said that earth-worms and the grubs or larvæ of certain insects constitute the principal food of the mole, and the quantity of these which each individual destroys must be enormous. Blasius states that a mole will consume its own weight of food daily, and from observations on one kept in confinement we are convinced that this is no exaggeration. But the animal by no means confines itself to its usual bill of fare; often, especially in warm nights in summer, it ventures out of its burrows and comes on the surface in pursuit of snails and slugs. If a mole meets with a snake or a frog on one of these excursions it attacks it with the greatest fury, and drags the struggling reptile down into its den, to be devoured at its leisure. Like most insectivorous animals, it always attacks from behind, and its favourite morsel appears to be the entrails of its victim. The captive mole alluded to above killed and devoured several frogs, which he always first seized by the hind legs; and Blasius has witnessed similar attacks in a state of nature. Toads are rejected, but mice or shrews are at once seized, and other moles when slain in battle are promptly devoured by the conqueror. With this fierce and voracious appetite the mole is singularly incapable of supporting hunger—twelve hours' deprivation of food is said to be fatal. It may be conceived, therefore, that it has to work hard for its living, and this is especially the case in winter, when its prey is driven to a greater depth than usual by the cold, and it is obliged to form new runs in pursuit. Its labours at this season may often be traced by the fresh mole-hills thrown up through the frozen earth and snow.

During the greater part of the year, the mole lives a strictly solitary life, confining itself mostly to its own fortress and hunting-grounds, and fiercely resisting any invasion by its neighbours, although portions of the same "high roads" may be used by several individuals. Early in spring, however, the male begins to seek the company of the fair sex, and often engages in deadly single combat with a rival suitor. The female brings forth four or five young ones (rarely six, or even seven), for which she prepares a special nest, usually at some distance from the citadel. There appears to be but one brood in the year, although young moles are to be found at various times, from April till Midsummer.

Although it is now well known that our common mole has keen, though very minute, eyes, yet the older naturalists had something to go on when they described it as blind, for the mole of Southern Europe—the only one known to the classic writers—has its eyes covered by a continuous though very thin and semi-transparent skin. In general appearance this blind mole* very much resembles our native species, and its habits are described as similar. Its runs and alleys are said, however, to be shallower, and it is stated by some writers not to make any mole-hills. Several other species of *Talpidæ* are known from the more northern parts of Asia, and a few allied forms are natives of North America, but no true moles are natives of South America, India, or Africa. In the south of the latter continent their place is occupied by the so-called "golden moles," which differ considerably in their structure, and constitute a distinct family—the *Chrysochloridæ.* They resemble the true moles in their general form, but have almost rudimentary tails, and their fur has a curiously brilliant metallic lustre, whence they derive their name.

Fig. 6.—The Mole-Rat (*Spalax typhlus*).

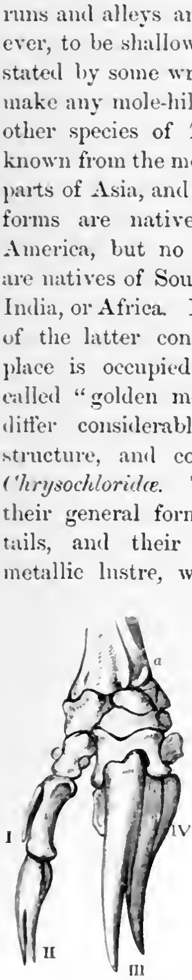

Fig. 5.—Bones of the Fore-paw of the Golden Mole. (*After Owen.*)

In the structure of their fore-limbs they differ much from the *Talpidæ ;* their shoulder-blades and collar-bones are formed more on the usual model, but their fore-paws are very peculiar. One of the small bones of the wrist (the *pisiforme*) is developed into a long shaft, which runs up to the elbow and seems at first sight to be a third fore-arm bone (Fig. 5, *a*), while of the four digits the two middle ones (II, III) are developed to an unusual size, especially the third finger, which is armed with an enormous deeply-cleft claw. Such a fore-foot is evidently a powerful digger, and accordingly the golden moles appear to be almost as adept excavators as their sable cousins.

Turning to the great order of Rodents, or gnawing animals, we find a few forms which are of strictly subterranean habits. But as these are not carnivorous, it is not necessary that they should possess the rapidity of underground movement essential to the mole; and, in consequence, we find no such extraordinary modifications of the bones of the fore-limbs as we have considered above. Their bodies, however, are always more or less cylindrical; their eyes and external ears very small, or even rudimentary; their limbs short but powerful; and their fore-claws strongly developed. One of the most typical genera is composed of the mole-rats, the best-known species of which (*Spalax typhlus,* Fig. 6) is common in Eastern Europe. In this animal, as in the Italian mole, the eyes are not only extremely minute, but are covered by the skin. Like the moles, it forms long branching galleries, of which those used in feeding run close under the surface, so as to intersect the roots of the plants which grow above. These roots are severed by the mole-rat's great incisor teeth, and the more succulent kinds are devoured, while the fibrous parts of others are carried off to form its nest, which is placed at a greater depth, for safety. Unlike many other rodents, it neither hibernates nor lays up a store of winter food; at that season it seeks deeper-

* The *Talpa cæca* of Savi.

rooted plants on which it can feed below the stratum of frozen earth, or, in default of such, it forms superficial runs under the protection of the snow. Belonging to the same family as the mole-rat are several other genera, all of which appear to have very similar habits, although some are less exclusively subterranean than others. The coast-rat of South Africa (*Bathyergus maritimus*) is called *zand-moll*, or "sand-mole," by the Dutch Boers, and presents a curious analogy to the golden moles of the same country in the prismatic reflections which adorn its fur in a live state. It inhabits the sandy plains near the coast, where it forms great systems of branching galleries, diverging from a central point. These are often very dangerous to travellers, the ground being so undermined that it often gives way under a horse's feet, and causes it to fall heavily with its rider. The coast-rats are also most destructive beasts when they invade cultivated ground, in which case the Boers are in the habit of destroying them by means of a spring-gun, trained so as to enfilade a run, and discharged by a cord connecting the trigger with a turnip, or some other similar bait. Another North African genus (*Heterocephalus*) is peculiar in having the entire body almost totally naked, only a few scattered and very minute hairs being present.

In North America we find subterranean rodents belonging to quite a distinct family (the *Geomyidæ*), and known as gophers, pouched-rats, or salamanders. Their most striking peculiarity, which they share with a few terrestrial allies, is the possession of cheek-pouches, which open on the lower side of the jaw, outside of the lips, and which have no connection with the cavity of the mouth. These are used by the gophers to convey their food to their dwellings, and also, as some writers assert, in removing the refuse soil from their burrows; but the latter statement seems to require confirmation. The species most recently observed has been the Florida gopher (*Geomys tuza*),* which abounds in the "barrens" and cultivated grounds of Georgia, Florida, and Alabama. Its "runs" form subterranean labyrinths, the position of which is indicated by the large heaps of sandy soil which it throws up at intervals of three or four feet, and so rapidly are they excavated, that Professor Brown-Goode has seen *thirty* such hillocks thrown up on the line of a tunnel in the course of a single night. Side-passages from the main corridors lead to large chambers, some of which are lined with grass and leaves, and used as nests, while others serve as store-rooms, in which supplies of food are amassed. The gophers are particularly fond of sweet-potatoes, and nothing delights them more than to gain access to one of the thatched heaps in which agriculturists are in the habit of storing these esculents. "The salamanders are cunning enough not to throw up sand-heaps in the vicinity of these potato-heaps, but remove the loose earth into their old tunnels. When they once get access to the 'tater-hake,' they quickly remove its contents, and the owner wakes up some morning to find his *cache* a hollow pretence." By keeping gophers in confinement, Professor Brown-Goode was enabled to observe their method of burrowing, which appears to be very similar to that of the mole. They grub the earth with their noses, and shovel it away with their strongly-clawed fore feet, scratching at the same time with their hind feet so vigorously that the soil is cast several inches behind them. Roots or twigs are soon disposed of by their large and trenchant incisors. When a certain amount of loose earth has accumulated, the animal turns round, joins his fore-paws before its nose, "transmutes himself into a sort of wheelbarrow," and pushes the soil before him till he reaches the nearest heap, where it is thrown up on to the surface. They appear to be dull and stupid beasts, but are extremely pugnacious, the males engaging in single combat with wonderful ferocity.

South America presents us with another remarkable form of burrowing rodent, belonging to a totally distinct family from either the mole-rats or the gophers. This is the genus *Ctenomys*, one of the *Octodontidæ*. Several species have been described, the best-known being the Tucotuco (*C. braziliensis*), the habits of which have been carefully observed by the greatest of modern zoologists. Mr. Darwin found the animal extremely abundant near Maldonado, in the Argentine Republic. A stranger to that country is often greatly astonished and puzzled at hearing a strange sound, apparently produced quite close to him, without there being any cover at hand to conceal the producer. The sound is a short grunt, repeated four times in rapid succession, and in constant musical time, and is imitated by the syllables *tu-co-tu-co*. It is the voice of a small rat-like rodent, uttered in its burrow, possibly just below your horse's feet. The Tucotucos prefer dry and sandy soils in general, though they are sometimes found on the borders of lakes, and feed on various

* The best account of the habits of these curious animals is from the pen of Professor Brown-Goode, published by Dr. Elliott Coues, in the report of the United States Survey of the Colorado River.

roots, in search of which they make their extensive burrows close beneath the surface of the earth. They throw up small hillocks, less than an ordinary mole-hill, and are said to store up supplies like the gophers, whose habits we have already noted.

Such are the principal types of mammals which lead a truly subterranean life. Those which live in burrows, but come habitually to the surface in search of food, are not less interesting; but present too large a subject for our present consideration.

THE MARINER'S COMPASS.

By William Durham, F.R.S.E.

The early knowledge of elementary scientific facts, and the slow progress of their investigation and practical application to the wants of civilised life, are well illustrated in the history of the compass.

The ancient Greeks and Romans were quite aware of the attracting power of native iron magnets, or loadstones, and also that this power could be communicated to iron, and retained by it for a length of time. No one amongst them, however, had ever noticed the behaviour of an elongated bar of magnetised iron suspended by a cord or floated in water, and to this oversight must be attributed the lateness of the discovery of "terrestrial magnetism," and the long period that elapsed before the compass was used by Europeans as a guide over the trackless paths of ocean.

That remarkable people, the Chinese, seem, however, at a very early date, to have used the directive power of the compass to guide them in their journeys over the vast plains of Tartary. They made little images, whose arm, moved by a freely suspended magnet, pointed continually towards the south. An apparatus of this kind, called *fsenan*, or "indicator of the south," was presented to ambassadors from Cochin China, to guide them in their homeward journey, 1,100 years before our era. The knowledge the Chinese thus possessed seems to have gradually travelled westward by means of the Arabs and Crusaders, but it was fully 2,000 years afterwards before it was fairly applied among the nations of Western Europe.

Since then, owing to its practical value and scientific interest, terrestrial magnetism has formed one of the most attractive and, at the same time, most difficult subjects of scientific investigation, and promises to lead to results of the highest importance in our knowledge of the arrangements of Nature.

The immense stimulus which the application of the compass gave to navigation, and consequently to intercourse between distant lands, may be appreciated when we remember that, before that, sailors, having only the positions of the sun and stars to guide them, were completely bewildered when these were hid by clouds or storms, and consequently were afraid to venture on the open sea away from the sight of land.

In a seafaring nation like our own, the "mariner's compass" is an object familiar to almost every one, and may be very briefly described.

A magnetic needle is attached to the underside of a circular card of some semi-transparent substance, such as talc. On this card is engraved a radiating diagram, dividing the circle into thirty-two parts, called points. The needle, with the card attached, is delicately balanced on a central pivot, round which it is free to move in a horizontal plane. The position of the card, of course, indicates the position of the needle below.

The needle and its support are inclosed in a small metallic box, which is hung so as to preserve its horizontal position notwithstanding the rolling or pitching of the ship. This is accomplished by means of *gimbals*, which are two metallic rings one within the other; the compass-box is swung on the inner ring by two small supports diametrically opposite, and the inner ring is, in its turn, supported on the outer one in a similar manner, but the points of support are at right angles to those of the box, as shown in Fig. 1, where A A are the supports of the compass, and B B those of the inner ring.

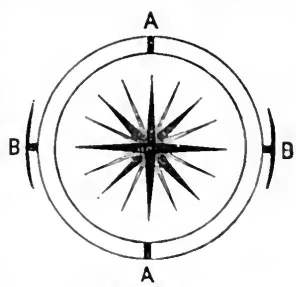

Fig. 1.—The Magnetic Needle and its Supports.

The whole is fixed in the top of a strong case, called the *binnacle*, firmly secured to the deck of the ship. The binnacle has a pane of glass in front by which light

may be admitted at night to illuminate the interior. The whole is shown in Fig. 2, K being the glass in front.

In the practical use of the compass it is necessary that we should know and guard against certain disturbing influences on its direction, lest the very

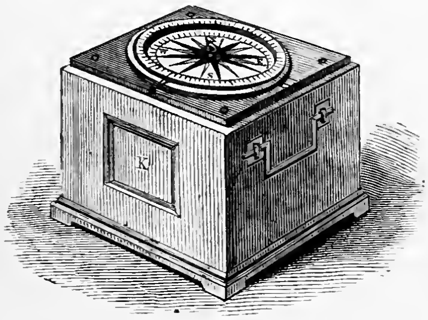

Fig. 2.—Compass in the Binnacle.

means the unwary sailor takes to insure his safety may lead to his shipwreck and death. One or two experiments will make these plain.

(1) If another suspended magnetic needle is brought near the compass, we shall find that the ends of the two needles which point northward will *repel* one another, while the end of the one needle which points south will *attract* the end of the other which points north.

(2) If any piece of iron or steel is brought near either end of the compass-needle, the latter will be attracted out of its proper direction. This we know to be due to what is called the inductive power of the magnet acting on the iron, and endowing it with temporary magnetic power, when mutual attraction is set up.

These actions between magnets and iron are exactly analogous to those between electrified bodies, as described in this work (Vol. I., p. 45).

(3) If any piece of hard iron or steel is allowed to remain in contact with a magnet for some time, it will acquire the properties of a permanent magnet, and be capable of attracting or repelling the poles of the compass-needle as described above.

These three experiments point out at once the manner in which the earth acts on the direction of the compass, and the source of those disturbing influences to which we have referred. As the compass-needle always swings round to its north and south direction when it is free to move, it is evident that the northern part of the earth possesses the properties of the south-pointing pole of the needle, as it attracts the north pole, and also that the southern part of the earth possesses the properties of the north pole of the needle: that it is, in fact, just a large magnet with the poles turned in opposite directions to those of the compass, or, to use a common expression, "turned end for end."

The earth, therefore, is capable of inducing temporary or permanent magnetism on iron or steel, as described in experiments (2) and (3).

As many of our ships are entirely built of iron, and all of them contain more or less of that metal in their structure, it becomes a question of great importance to know how to avoid the danger of any magnetism, temporary or permanent, induced by the earth's action, so disturbing the direction of the compass as to mislead the navigator.

The inductive action of the compass-needle itself can be pretty well guarded against by having it small and placed at such a distance from any ironwork that its effect may be practically of no moment.

The earth's action, however, cannot be so easily disposed of, and various methods are adopted for correcting the compass so as to know the true direction due to the earth's magnetism acting directly on the needle. To correct for any permanent magnetism, the ship is brought into such a position that the needle points to the true magnetic north and south, or is in the magnetic meridian of the place of observation; the ship is then turned gradually round on its centre as a pivot, turning, say, from north to west; if there be any permanent magnetism in its iron the compass will be moved gradually away from its position towards the one side or other of the meridian. As the vessel gradually turns towards the south, the needle also will gradually regain its first position; again, as the vessel continues turning towards the east, the needle will deviate in the opposite direction to its former movement, again returning to the magnetic meridian as the ship returns to its first position. The arc which the end of the needle thus describes to the one and the other side of the magnetic meridian is a measure of the magnetism of the ship, which can, therefore, be allowed for when observations are made at sea. The correction for temporarily induced magnetism is a much more difficult problem, as that is continually changing in amount and direction, according to the relative position of the ship, its cargo (which may be composed of magnetic material), and the magnetic lines of force of the earth. The principle employed, however, may be explained as follows. The variation of the compass caused by the influence of the vessel and its cargo having been determined in the manner just

described, the compass is taken on shore, and placed upon a wooden pillar capable of being turned round in a horizontal plane in the same manner as the ship; pieces of iron are inserted in this pillar in such a way that their effect on the compass, when the pillar is turned round on its axis, is exactly the same as that produced by the ship, &c. The pillar, and the compass on it, are now both transferred to the ship, and if the latter is now turned round as before, it is evident the effect on the compass will be doubled. To know, therefore, the amount of correction requisite at any time, it is only necessary to note the position of the compass, and then remove the iron from the pillar, when, of course, the needle will go back towards its proper direction. The amount it goes back just requires to be doubled to give its true position. Thus, if it goes back 2°, its true position is 4° from that observed before the iron of the pillar was removed.

Having pointed out the precautions necessary to be taken in the use of the compass as a guide, we now come to the consideration of "terrestrial magnetism," on a correct knowledge of which the value of that instrument mainly depends. If the earth were a regular magnet, like a symmetrical bar of magnetised steel, the compass would everywhere be directed due north and south; the magnetic and geographical meridians would coincide, and there would be no *declination* (Vol. II., p. 3). It was early discovered, however, that no such simple arrangement obtained, but that the compass almost everywhere deviated more or less from the true north and south directions. In this country it points about 23° west of the true north. The discovery of the fact was at first hailed as of immense importance to navigation; it was imagined the longitude of a ship at sea might be determined by the declination of the compass alone. It is said that Sebastian Cabot boasted on his death-bed of having this knowledge through "special divine manifestation." The idea of the early navigators can be readily understood. In 1492 Columbus discovered in the Azores a position of *no declination*, or where the compass pointed due north and south, and it was imagined that the declination increased in a regular manner from this position. Suppose the compass deviated one degree for each 100 miles east or west from this point, then the mariner could easily tell how many hundred miles he was distant from the point by noting the number of degrees the compass had deviated.

As observations on declination were multiplied, however, the hope of the early navigators was dissipated, for it was found that the phenomenon was exceedingly irregular; and if the points of equal declination were joined by lines, after the manner of geographical meridians, as laid down in maps, these lines were of an exceedingly irregular and wavy form, so that the declination of the compass at any particular spot could only be known by actual observation, and until the whole surface of the world had been mapped out the declination of the needle could not be used as an exact indicator of the longitude.

In 1576 Robert Norman directed attention to the dipping-needle as a means of investigating the distribution of the earth's magnetism. This instrument measures, not the *deviation of the needle from the true north and south line*, but the *inclination or angle which its deviation makes with the horizontal line*, when it is free to move in a *vertical* plane (Vol. II., p. 3).

This method may be understood if we observe the behaviour of such a needle when placed in various positions over a large bar-magnet. When at the centre it will have no dip, but be quite horizontal; but as it is carried towards either pole it will incline more and more, until it becomes vertical at the poles themselves. Fig. 3 will illustrate this. The middle

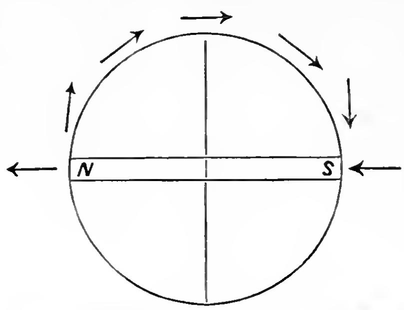

Fig. 3.—Illustrating Direction of the Dipping-Needle.

point, where the needle is horizontal, may be termed the magnetic equator.

Investigating the earth's magnetism in this way, it was found that the inclination generally increased from the equator to the poles, and sanguine hopes were entertained that the latitude might be determined by its means: just as similar hopes had been entertained regarding the determination of longitude by means of the declination; but the same cause dissipated the hope in both directions—viz., the extreme irregularity of the distribution of the earth's magnetism. The lines forming the points of equal inclination were found to be as irregular as in the case of declination, and the magnetic equator was

not a large regular circle coinciding with the geographical, but passed round the globe, sometimes north and sometimes south of the latter, and cutting it in two, or perhaps four, places, but not coinciding with it to any extent. Locally, however, the inclination may be, and has actually been, used by vessels in darkness or mist to determine whether they were north or south of a port they wished to enter.

By the aid of the dipping-needle, however, the positions of the north and south magnetic poles or points, where its direction is vertical, have been determined. The north magnetic pole is found to be in latitude 75° 5′, and longitude 96° 46′ west, and the south pole in latitude 75°, and longitude 138° east. They are not, therefore, diametrically opposite, and no straight line can be drawn between them and referred to as a magnetic axis analogous to the geographical axis of the earth.

The two methods of investigation just described depend on the *direction* of the needle; a third method, however, due mainly to the illustrious traveller Humboldt, remains to be mentioned. This has reference, not to the direction, but to the *intensity* of the magnetic force at different parts of the earth's surface. If we cause a magnetic needle to oscillate backwards and forwards near a large magnet, we shall find these oscillations to increase in rapidity as the needle approaches the magnet or as the strength of the magnetism increases; and we know that the force increases in proportion to the square of the number of oscillations in a given time. Thus, if at one place of the earth's surface the number of oscillations is ten, and at another seven in the same time, we know that the force at the one place is to the force at the other as one hundred is to forty-nine, or as two is to one, nearly.

The results obtained by investigating the distribution of terrestrial magnetism by this method agree with those obtained by observing the declination and inclination, for while the intensity generally increases from the equator to the poles, the increase shows the same irregularity as observed in the other phenomena.

The study of these various phenomena is greatly complicated by the fact that none of them is constant; they are all subject to incessant change, mostly of a regular periodic character: that is to say, the needle does not always exhibit the same declination or inclination, nor does the intensity of the magnetic force always remain the same at the same place. These changes are ceaseless and complicated, and their study is attended with great difficulty; but as the result of many careful observations, it appears that some of them depend on the time of day, some on the season of the year, &c., while others of a sudden and irregular character, when the needle is simultaneously affected over thousands of miles of the earth's surface, appear to coincide with the outburst of spots upon the sun's surface. In the northern hemisphere the north pole of the needle commences to move westward about 8 A.M., and continues to do so till about 2 P.M., when it turns suddenly, and moves back again towards its starting-point, which it reaches about midnight. During the night it repeats the movement, although on a smaller scale. So regular is the movement, that between the tropics the hour of the day may be known from the position of the compass-needle. Recently another movement, of an analogous nature, but which takes twenty-six days to complete, has been recognised; this time is just about the same as the sun takes to go round its axis. Another periodic movement seems to coincide in time with the eleven-years period of maximum and minimum sun-spots.

Besides these whose periods have been recognised, there is a slow secular change, which has been going on for nearly 300 years, but whose cycle is not yet complete. Thus, in 1657 the compass-needle pointed due north and south at London; since then it has gradually turned westward, and in 1800 it pointed 24° 36′ W., and it is now as gradually returning to the east again. The following table exhibits the character of the change, which is of the same nature as those of the shorter periods.

CHANGE OF DECLINATION AT LONDON.

Year.	Declination.	Year.	Declination.
1580	11° 17′ E.	1760	19° 30′ W.
1622	6 12	1774	22 30
1634	4 5	1790	23 39
1657	0 0	1800	24 36
1666	0 34 W.	1806	24 8
1672	2 30	1815	24 7
1700	9 40	1820	24 11
1720	13 0	1831	24 0
1740	16 10		

The cause of terrestrial magnetism is not yet satisfactorily explained. It is evident that we cannot consider the earth as a body regularly magnetised, but rather as made up of an indefinite number of small magnets, the general result of whose action is directed north and south. Until lately, it was supposed that only iron, nickel, and cobalt were capable of exhibiting magnetic phenomena, and the magnetism of the earth was attributed to large masses of these existing in the interior of the globe; and, no doubt, there are large mountain masses

capable of acting powerfully on the magnetic needle. The researches, however, of Faraday, Weber, and Tyndall have established the fact that all substances are capable of being rendered magnetic, and the phenomena exhibited seem to depend more on the physical state, as regards pressure, &c., than on the chemical nature of the substance. We may, therefore, suppose either that, owing to pressure, &c., the whole body of the earth is rendered magnetic permanently, or that it is rendered temporarily so by the inductive action of some body external to itself. There is one great difficulty in the way of such explanations, however, in the fact that all traces of magnetism disappear from all substances at a high temperature. Thus, iron at a bright red heat ceases to give the least indication of its presence. As the interior of the earth must be at a very high temperature, it is difficult to understand how it could become magnetic, unless the great pressure modifies the action of heat on magnetism to a large extent.

Many theories have been advanced to account for the variations in the magnetic elements of declination, inclination, and intensity which we have noticed, but none are satisfactory and complete. It is very evident, however, that in this, as well as in many other of the grander phenomena of Nature, we must not confine our attention to the earth itself, but must consider the action of external bodies, and especially that of the great centre of the solar system. The coincidence in time of many of the variations with solar phenomena irresistibly leads us to attribute to its action much of what we observe, and we shall point out one or two ways in which that action may be exercised. First, we may suppose the sun itself to be a magnet acting inductively on the earth, and of course his varying condition, distance, and relative position, would produce corresponding changes in the earth's magnetism. To this explanation there are, however, great objections. From the fact we have mentioned —of a high temperature destroying the power of magnetism—it seems almost impossible to conceive that such a body as the sun can be magnetic: and, besides, it has been proved, from a mathematical investigation of the subject by Messrs. Chambers and Stoney, that the variations observed in the earth's magnetism cannot be accounted for by the magnetism of the sun or moon, supposing these bodies to be magnetic.

It would seem, therefore, that the sun cannot act in this direct manner. It may act, however, indirectly by means of the heat which it radiates towards the earth's surface. If we take a ring composed of two metals—say iron and copper—joined at two points, and heat one of the junctions while the other is kept cool, we shall find that a current of electricity will circulate round the ring. Now we know that a current of electricity passing in this way acts exactly like a magnet (Vol. I., p. 47). It is supposed that the sun acts in this way on the earth as it revolves, causing currents of electricity to circulate on its surface, producing magnetic action. These currents have been proved by observation really to exist, but on measuring them accurately they are also found totally inadequate to explain the phenomena observed.

One of Faraday's most brilliant discoveries—that oxygen gas, which composes about a fifth of our atmosphere, was really capable of being rendered magnetic, like iron—was eagerly seized upon as a possible cause of magnetic variation. He found that the amount of magnetism induced upon oxygen depends on its density; that, again, depends on its temperature, as it expands when heated, and becomes, of course, less dense. It was conjectured that, being expanded by the sun's heat, its lessened magnetic inductive power would react on terrestrial magnetism, and produce the variations observed in the latter. This ingenious explanation cannot be considered as more satisfactory than those already mentioned, as many of the phenomena to be accounted for do not occur at the time nor to the extent we should expect if the explanation were complete.

Recently, Professor Balfour Stewart has suggested another possible mode of the sun's indirect action. We know that if any body is moved across magnetic lines of force (Vol. II., p. 3), electricity is developed; and he says that the sun's heat causes convection-currents in the upper regions of the atmosphere, and these currents, cutting through the lines of force of the earth's magnetism, develop electricity, which reacts on the earth and produces the variations of the magnetic elements.

There is no doubt the sun's heat may, and probably does, affect the condition of the earth's magnetism in the indirect ways we have noticed; but no one of them, nor all of them together, seem to offer a satisfactory solution of this very complex problem. They offer no explanation of that slow secular movement we have referred to as having been observed since 1580, and whose cycle is not yet completed. There is also a difficulty in the way of all heat theories in the fact that there is well-marked variation in the earth's magnetism, due to

the moon's influence; and as the heat from that satellite is quite inappreciable, it seems impossible that the explanation sought can be found in that agent.

It must be admitted that our knowledge of "terrestrial magnetism" is confined entirely to the observations made in various parts of the earth, and these are by no means complete. We have not as yet mapped out the distribution of the earth's magnetism over its whole surface, but only at isolated stations. We can but hazard a probable conjecture as to the cause of the magnetism itself; but as to its variations, we must confess that all our theories fall short of a complete explanation.

The study of the mysterious movements of the compass-needle has thus led us over a wide field of inquiry; it has shown us that the earth is indeed magnetic, but presenting the phenomena of an indefinite collection of small magnets irregularly distributed rather than those of a regular large magnet; it has shown us also that the magnetism is subject to incessant wave-like movements, some of them taking hundreds of years to complete and others only a few hours. We are obliged to confess our inability to unravel all the mysteries disclosed to us, but we are urged by the attractiveness of the inquiry to pursue our investigation. We feel assured that the sun is in some way connected by a magnetic bond to this little world of ours, as every movement he makes or outburst that takes place on his surface is instantly registered by the tiny needle. Possibly, there may be some hitherto unrecognised form of solar energy yet to be discovered by the student of science; but whether this be so or not, the close connection, if not absolute identity of electricity and magnetism, the probability of light being a magnetic phenomenon, and various other matters, render the inquiry full of promise.

Owing to its practical value in navigation, many Governments have lent their aid in investigating this subject, and numerous observatories have been established all over the world, where thousands of observations are made every year by competent workers; and it cannot be long before Nature will yield up her secret, as she always does, to persistent and well-directed effort, and then another field will have been wrested from the region of the unknown, and added to the ever increasing domain of physical science.

SPIDERS' WEBS.

By Arthur G. Butler, F.L.S., F.Z.S., etc., British Museum.

Most persons have often seen the geometric web of our commonest genus of spiders, and in all probability the majority of them have regarded it with disgust, neither knowing nor caring to know how it was constructed, but despising it as the work of a creature which is almost universally looked upon with feelings of loathing, and forgetting that nothing which exists is too mean for study if it be the workmanship of a perfect Creator.

Moreover, in the present age of inquiry it does not suffice for any thoughtful person to be contented to know merely that this thing or that exists as a manifestation of the operation of natural laws; he must also ask himself how the result which he sees has been arrived at, by clear reasoning and patient investigation expanding his mind, and thus rendering him a better and more intelligent companion to his fellow-men.

Let us suppose, then, that our readers are unconscious of any fact in relation to the spider excepting that it makes a web; they are, nevertheless, anxious to learn, not slow to observe natural phenomena, and patient in unravelling all mysteries which obscure their mental vision. To these I offer the results of some years' study of the various spiders common to our gardens, beginning with the commonest and best-known species (*Epeira diademata*), the constructor of the familiar geometric web.

The first thing that puzzles the observer as he strolls round his garden is the fact that the direction of the webs indicates, to a great extent, from what quarter the wind is blowing, and whether there be much or little of it: this he is at first inclined to attribute to a natural instinct on the part of the spider; but he is at a loss to understand why only the greater number of the spiders in his garden, and not all of them, seem to have inherited this natural gift. In order to determine the point, he must begin at the beginning, and watch the construction of the snares from the first thread spun: otherwise, he will remain in ignorance.

Generally speaking, *Epeira diademata* (Fig. 1) spins her web in the early morning, somewhere between six and eight o'clock; our student therefore, if he rises at six some fine autumnal morning, will have ample opportunities of watching its *modus operandi*. At first he sees it running over the twigs and leaves in a vague manner, until, as it reaches some projecting point, it suddenly drops over the edge and hangs suspended in mid air; likely enough, soon after this, the student will see a rapid movement of the spider's anterior legs, and then, to his horror, will perceive it rushing up a line towards the brim of his hat. Here is another puzzle: he has entirely failed to see how the line became attached or where it came from. Unless he solves this problem the first difficulty will not be cleared up; therefore, let him begin again, and this time stand out of the way of the spider's silk and his own light.

Letting the clear sunlight fall upon his second spider, the observer notices that immediately after her descent from the twig or projecting leaf, there is a movement of the posterior legs towards the spinnarets, and then, to his surprise, he discerns a quickly expanding fan of multitudinous delicate silken threads floating outwards from the spider's body: the action is so rapid that one can scarcely believe the silk to be drawn out of the spinners; it appears to be forcibly expelled by muscular action.* The whole of these threads are extremely glutinous, and adhere to the first object with which they come in contact; their direction is, of course, decided by the lightest breath of wind: consequently, if the wind

Fig. 1.—Epeira Diademata.

* The Rev. O. P. Cambridge, to whose article in the ninth edition of the "Encyclopaedia Britannica" I am indebted for several important facts, informs me that muscles for this purpose do exist.

be from the south, the centre of the silken fan will be directed in a southerly course from the spider's body.

Directly that one of the fine silken lines adheres to any object, the *Epeira* turns and pulls upon it with her anterior legs to test its strength; and if satisfied, she immediately runs across and thickens it, sometimes rolling up the unattached threads upon the way, but frequently cutting them loose and allowing them to float away as a sport for the winds. This, as it seems to me, will account to some extent for the existence of "gossamer," "fils de la Vierge," or "fliegender sommer," which has been the theme of many a learned memoir and the cause for many a superstitious fancy.

> "As sore wondren som on cause of thonder,
> On ebbe and floud, on gossomer, and on mist,
> And on all thing, til that the cause is wist."—*Chaucer*.

It is thus, then, as I can testify from oft-repeated observations, that the spider, when necessary, forms an upper or foundation line for its snare; if a lower foundation be required, it is carried from the point of attachment of the first, along which the spider runs with it to the opposite extremity; thence (still holding it clear with one of her hind legs) she descends to some distance, and there fixes it, thus inclosing a large triangular area; the remaining boundary lines are formed by dropping from one point to another, the thread being fixed here and there at intervals until the circumference of the web is completely inclosed. The direction of the web, therefore, is determined by the wind, not by the will of the spider, since the position of all the circumferential lines is decided by the course which the foundation line takes. Before, however, leaving this part of the subject, we must discover why on one morning many of the webs are placed above the garden wall, and on another morning all are below it. The reason for this is obvious: if the wind is violent, the spider takes advantage of the protection afforded by the wall; if there be no wind to float her fan of silk, she seeks the highest point to court the passing zephyr.

But to resume the thread of our web. No sooner is the frame for the snare completed than a diagonal line is spun across it: sometimes by a simple drop from one side to the other; but when (as sometimes happens) the foundation is oblique, by carrying the line round from one side to the other, there winding it in, and fixing it. This being accomplished, the spider proceeds to about the middle of the thread it has just spun, fixes a second, and carries it to the circumference; runs with it for a short distance along the boundary line, fixes it, returns up the latter to the centre; fixes a third, and so on, each time travelling to and fro upon the line last spun, until the whole area is filled with a series of nearly equidistant silken radii.

The next labour is to convert the rays into silken ladders; this is effected by the spider beginning near the centre with a line which is carried in a spiral form, producing a series of continuous concentric circles, and fixed with a minute drop of gluten to each of the rays. This line is not carried to the boundary, but at some distance from the centre a second is commenced, formed of extremely viscid silk, upon which the gummy secretion is distinctly visible, with the aid of a lens, in the form of closely-approximated globules of amber-coloured glue. It is said that when the viscid lines are completed the spider cuts away the unadhesive lines; but this I have never observed, and I have watched spiders for months together, petting, feeding, and trying experiments with them every morning.

The centre of the web is attached by several very strong threads to some leaf or twig near by, which is bound together by a canopy of silk, and forms the den of the spider. Here she sits, with her anterior legs upon the threads, alive to every movement of her snare, not judging by the sight of her eight eyes, but by the sense of touch.

> "The spider's touch, how exquisitely fine!
> Feels at each thread, and lives along the line."—*Pope*.

Thus, then, we have seen how the common *Epeira* spreads her net; but there are other spiders, nearly as abundant, whose webs are entirely different in construction; indeed, Latreille classified the *Araneidea* by the form of their webs as follows:—

Orbitelariæ.—Web a circle, or a portion of one, with lines radiating from a centre.

Retitelariæ.—Where a thin sheet of web is suspended among the branches of shrubs or in angles of buildings, and held up and down by lines in all directions above and below.

Tubitelariæ.—Where the snare is a silken tube, inserted in crevices, fissures, and casual holes, and with an open mouth, more or less guarded or armed with insidious lines.

Territelariæ.—When a tube is spun in a hole formed by the spider itself, and closed sometimes by a close-fitting, cork-like, or occasionally scale-like or wafer lid, at times left open, but not unfrequently closed by the falling over of a portion of the tube which protrudes from the surface of the ground.

Next to the web of the geometric spider, which, of course, belongs to the *Orbitelariæ*, that of *Agelena labyrinthica*, one of the *Tubitelariæ*, will be most familiar as a garden curiosity. This spider usually spins its snare in rockeries, but on one occasion I found it constructed among the leaves of a laurestinus. The web, when fresh, is by no means unornamental: the main body of it consisting of a slightly concave sheet of densely woven flocculent silk, the surface of which is very sticky, being, probably (as in the adhesive web of *Amaurobius*), spun from the fourth pair of spinners, and carded or teased by means of the *calamistrum* (Fig. 2), or double series of curved bristles, along a portion of the upper surface of the metatarsi of the fourth pair of legs, so that, from its minutely divided and elastic fibres, it becomes adhesive.

Fig. 2. Calamistrum (c) of *Amaurobius*.

The posterior portion of the web consists of a cylindrical tube, in which the spider sits, with its back to the entrance and its posterior legs extended, so that (by means of the sense of touch) it may obtain intelligence of the capture of a victim.

Although one of the most savage of all spiders in its attacks even upon bees, or spiders of other species which may chance to fall into its clutches, I have several times been astonished to find that two examples, differing somewhat in size, occupied the same web; and that when, watching my opportunity, I have knocked one spider out of the canopy for closer examination, a second has rushed out and seized the insect which I have used as a bait. The Rev. O. P. Cambridge has, however, kindly informed me that this is a species in which the sexes dwell together in concord, not showing any tendency to devour one another; as is unhappily the case with many other spiders.

The speed with which *A. labyrinthica* seizes its prey and drags it down into its den is generally so great that it is impossible to detect anything beyond a black shadow, which crosses the web and is gone like a flash. In order to get a closer view of the spider, one must either dash it out of the web or drop in as a bait a sturdy caterpillar of the "looper" tribe (*Geometrites*): the best, perhaps, is the leathery-skinned *Biston hirtaria*, a great black looking larva, common upon the trunks of lime-trees during the summer months. The moment this caterpillar begins to move upon the web the spider is up and upon it; but this species is not only very tough, but distasteful to insect persecutors, so that after one or two attacks, in which the spider is usually dragged along instead of the victim, the latter is permitted to march off unscathed. If the larva of *Abraxas grossulariata* be substituted, the spider succeeds in bearing it off, but soon becomes aware of its acrid properties, and drops it in disgust; so that the next minute the caterpillar may be seen taking great strides up the tubular den and over the canopy, whilst the disappointed tyrant makes no second attempt to capture it.

It was probably *A. labyrinthica* which inspired the pen of John Bunyan, the immortal allegorist, when he wrote—

> "My den, or hole, for that 'tis bottomless,
> Doth of damnation shew the lastingness,"*—

the tube being opened at both ends, and the spider having her face toward the lower opening: so that if poked out with a stick from above, she vanishes with all speed, and takes refuge in the nearest crevice until her pursuer has abandoned the chase, and then quietly returns to her snare.

It would be imagined that *Epeira*, from the ease with which she traverses her own viscid network, would easily escape from the toils of *Agelena;* this is, however, not the case: she moves upon it with much difficulty, and the approach of the enemy is so sudden and savage that, even when greatly superior in size and disposed to show fight, she invariably becomes the prey of her assailant.

I was once witness to an interesting stratagem practised by one *Epeira* upon another, and which, from certain points of similarity in the mode of attack to that of the *Tubitelariæ*, may be noticed here. I observed a large spider, apparently weak from want of food and unable to construct a web, wandering over the leaves of an *Aucuba* shrub; immediately below it was a good-sized web, in the centre of which was its owner, a spider even larger than the wanderer above it. As the object of my pity reached the extremity of the leaf which hung just over the middle of the web, she suddenly dropped into it, immediately behind its unlucky owner, and before the latter could turn to resent the intrusion, had seized her firmly. There was a desperate struggle, but to no purpose, as the attacking spider had the advantage, and never for one moment relaxed her hold until the other had ceased to move.

* "The Sinner and the Spider," in "Divine Emblems."

Another web, somewhat similar in character to that of *Agelena,* is found commonly in the crevices of old garden walls from which the mortar has fallen out; the architect in this case is *Amaurobius similis** of Blackwall. Instead of the silken canopy of *Agelena,* we here have an irregular adhesive network of silk upon the surface of the wall round the entrance to the den. The latter consists of a silken tube, which lines the hole or crevice, and which, consequently, is usually horizontal instead of perpendicular or oblique. As soon as any insect settles upon the sticky web surrounding the den, the fine elastic fibres of which it is composed adhere to its legs and wings, and the first struggle to escape brings the spider from her lair, into which she speedily drags her prey.

It must not be imagined that all spiders construct snares for the capture of their victims, for this is by no means the case. The little hunting spiders (*Salticus*), common upon walls and fences, depend upon their agility for their sustenance: running up and down, jumping over obstacles, and with the four great bulls'-eyes along the front of the cephalo-thorax always on the look-out for some unwary fly upon which they may spring. At first it was a puzzle to me how *Salticus* managed to spring upon the side of a wall without falling to the ground, but I soon discovered that she always carried a silken line with her throughout her wanderings, fixing it to the wall before each jump. †

Some of the *Thomisides,* again, obtain their prey by sitting perfectly still in the centres of flowers or on twigs, their bodies being so coloured as to resemble the calices or buds amongst which they are found.

The spinning-glands of spiders are, according to Carl Gegenbauer, ‡ forms of skin-glands which lie in the abdomen, and open by several pairs of papillæ placed behind the anus (spinnarets), producing a secretion which hardens into a "chitinous" filament when exposed to the air, and thus forms the thread of the spider's web (Fig. 3). The spinners are moved by special muscles, similar to those of the legs; they consist of from one to three joints, and vary greatly in size and structure, as well as in number; generally they are separate, but in *Tetrablemma* (Cambr.) they are inclosed in a kind of corneous sheath.

The legs of spiders are specially modified to enable them to traverse their webs. Each tarsus ends with either two or three more or less curved or bent claws, commonly (though not always) pectinated or finely toothed (Fig. 4); in some groups with other opposed serrated claws: the latter are also used as hooks, to give tension to the lines of their webs by alternately pressing and straining upon them; and lastly, as already stated, the *calamistrum,* or series of curved bristles on the fourth pair of legs in certain species, is used in the construction of the flocculent silk used for ensnaring their prey.

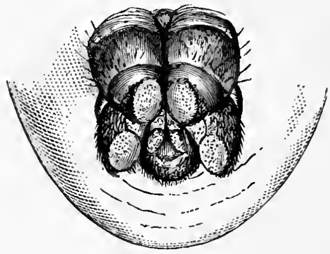
Fig. 3.—Spinnarets of *Epeira.*

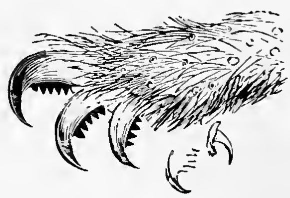
Fig. 4.—Spider's Claw.

Various efforts have been made from time to time to utilise spiders' silk in the manufacture of silken fabrics; but the difficulty of rearing spiders together, owing to their cannibal propensities, has hitherto proved an insurmountable barrier to the satisfactory accomplishment of this object. The possibility of making it into articles of apparel was demonstrated more than a hundred and fifty years ago, when silk obtained by Le Bon, of Languedoc, from spiders was woven into gloves and stockings. §

If anything is ever done in the way of utilising the silk of spiders, it will probably be obtained from the large exotic species of the genus *Nephila,* the silk of which is, in fact, used by ladies of the Bermudas for sewing purposes,|| and by the natives of the Island of Rodriguez in place of waxed-ends. The species of *Nephila* construct large geometric webs of great strength, in which (as I am informed) small birds are not unfrequently entangled, and which form no inconsiderable hindrance to travellers through a tropical forest, inasmuch as these spiders are said to build their webs close together

* I am indebted to the Rev. O. P. Cambridge for the name of the species.

† This explanation, however, fails to show how a flea accomplishes the same feat. Probably, in her case, the form of the jumping legs gives a curvature to her leap, thus bringing her back to the wall.

‡ "Elements of Comparative Anatomy," p. 250.

§ For an interesting account relating to Spiders and Spiders' Silk, see Charles Dickens's *Household Words,* vol. ii., p. 65.

|| *Zoologist,* 1858, p. 5922.

in communities, sometimes amounting to hundreds of individuals. Whether or not this last statement be correct, one thing is certain: namely, that the individuals of the various species are extremely abundant, and are often the only spiders sent home in a collection of spirit specimens.

If the preceding observations on the spider's web are insufficient to dissuade the reader from looking with horror and contempt upon these marvellous architects, let him at least remember that, though he may consider them as unworthy of his regard, history has ascribed to their agency the victories of Bruce, the preservation of Mahomet and of Du Moulin; and let him know that the man who cannot stoop to the study of that which is small will never be able to comprehend that which is great.

GLACIERS.

By Professor Barrett, F.R.S.E., M.R.I.A., etc.

IN a preceding paper * we traced the life-history of the Geyser; in the present we propose to follow, in like manner, the life of a Glacier, from its birth on the mountain-top to its grave in the valley below.

As every one knows, a glacier is a vast river of ice moving slowly down the mountain side, fed by the snow-fields above, and wasted by the warmth of the valley or sea at its lower extremity.

A region of perpetual snow is not, however, the only agent necessary for the production of a glacier; heat is equally essential, for snow is the result of the congelation of aqueous vapour, raised from the sea or ground by the action of the sun. The invisible vapour of water is always present, in greater or less quantities, in the air around us. When the temperature falls low enough, this vapour is deposited as dew, mist, rain, hoar-frost, or snow. It is only necessary to fill a metal can with a freezing mixture of snow and salt to cause a copious precipitation of the vapour present in the room upon the sides of the vessel, where it speedily becomes frozen into a thick covering of hoar-frost. In a similar manner the cold air of the mountain-top congeals the moisture contained in the winds that drift across its side, and thus its summit becomes clothed with a mantle of snow. In winter, the lowest point of the snow is found in the valleys; in summer it retreats higher up the mountain, but a certain well-marked boundary exists on every high mountain range, above which the snow remains unmelted all the year round. This is the so-called *snow-line*, where the gain of snow on the one hand, and the loss by melting on the other, are equally balanced. Above this line the gain exceeds the loss, and the residuum of unmelted snow is added to the yearly fall. It must not be supposed that *no* melting of the snow occurs above the snow-line; this is by no means the case; only the melting that occurs is insufficient to liquefy the whole of the annual fall.

* "Science for All," Vol. I., p. 225.

A brief digression here becomes necessary, as the question of the snow-line is one of considerable importance in connection with glaciers. It is commonly supposed that those places where the average temperature of the year is at or below the freezing-point will have a perennial covering of snow; but this is not so. There are, for example, regions in Siberia and North America where the average temperature is far below the freezing-point, and yet where the ground is not always covered with snow. This is to be accounted for either by the great intensity of the summer heat or by the extreme dryness of the air. It is, in fact, the temperature of the summer months that determines the plane of perpetual snow. It will, therefore, be obvious that the snow-line must descend as we pass from the equator to the pole; but in no inhabited region of the northern hemisphere does the snow-line descend to the level of the sea. In the Himalaya Mountains the snow-line attains an altitude of 16,000 feet; in the Alps some 9,000 feet; in Norway it varies from 5,000 to 3,000 feet, according to the latitude. In Great Britain the snow-line would be reached at an elevation of about 4,000 to 5,000 feet; but no British mountain attains this height. The influence of the dryness of the air on the level of the snow-line is conspicuously seen in the case of the Himalayas, the snow being upwards of 3,000 feet higher on the north side than on the south, or warmer, aspect. This is doubtless due, in large measure, to the extreme dryness of the plains of Tibet. So in Norway, although the average yearly temperature is higher on the coast than in the interior, the snow-line is nearly a thousand feet lower in the former

case. Inasmuch, therefore, as a glacier is fed by the snow-fields, it will be obvious that extreme cold, if accompanied by extreme dryness of the air, will be unfavourable to its formation. Thus it is that Siberia is destitute, it is affirmed, of all glaciers. The physical aspect of the country is also of some importance, for, obviously, isolated peaks would not allow the accumulation of sufficient snow to form a glacier.

As, above the snow-line, additional snow is yearly added to what remains on the ground, the tendency of elevated mountains is to rise higher and higher, and we may imagine this action continued for centuries, until at last all the water of our rivers, lakes, and seas would, by solar heat, have been distilled on to the mountain-tops, and converted into colossal peaks of snow. There would be, however, a limit to this action, for the upper regions of the atmosphere are devoid of moisture, so that snow could not be deposited above a certain altitude. In fact, were our mountains much higher than they are, there would be a superior, as well as an inferior, snow-line. The rapid growth of mountains that would follow a continued deposition of snow may be estimated from the fact that if three feet of snow were annually deposited above the snow-line (not an exaggerated estimate), this would make 1,879 yards, or upwards of a mile, added to the height of the mountain during the Christian era, if the yearly fall were unremoved. As we all know, however, our mountains have not this portentous growth. The heat of the sun, avalanches, and, to a slight extent, evaporation, come into play ; but the yearly fall is chiefly removed by the conversion of the snow into the glacier, different though they be in appearance. Ultimately, by its liquefaction in the valleys, the glacier restores to the ocean the water which may have been raised from its surface centuries before.

Hence, by the slow and continuous motion of the glaciers the vast reservoirs of snow on the mountain side harmlessly escape, and thus are prevented periodic cataclysms, which would otherwise ravage the now peaceful valleys. The avalanche, the messenger of death, gives place to the glacier, the messenger of life : for, literally, the glacier is such to the dwellers in these mountain valleys. Out of the wild ice wastes issue streams, most abundant in summer when most needed, which not only irrigate the valleys, but clothe the barren rocks with a deposit of fruitful loam ; for the glacier ploughs the mountain side, pulverising its surface, and thus bringing to the valleys a soil rich in food for plants. The fertile plains of the Rhine Valley can be distinctly traced to the "dust of ancient glaciers."

The collecting ground of the glacier is to be found in the upper valleys of the mountains choked with masses of accumulated snow. Of a very different character is this snow from the delicate crystals which originally fell. Pressed by the superincumbent weight, its surface melted by the sun, and the water formed trickling through its mass to freeze in the colder interior, the formerly loose and powdery snow becomes an agglomerated granular mass, growing more consolidated first in its deeper portions, and afterwards at its surface, as it travels further down the valley. This is the *névé*, which passes by insensible degrees into the glacier. As it descends still further, what was once incoherent and opaque snow becomes entirely converted into dense, and in many places perfectly clear, ice.

The change of the opaque *névé* into the transparent ice of the glacier is primarily due to the expulsion of the air entrapped between the particles of snow. Each individual snow-flake is perfectly transparent, and is separated from its fellow by a film of transparent air. Owing to the different refractive power of the air and the snow, a ray of light, in passing from one to the other, suffers partial reflection. A little light is therefore thrown backwards as it crosses from particle to particle of the snow. These reflected rays are again caught by other snow-particles in their path, and a portion of the incident light is again reflected. A luminous beam is therefore unable to struggle through the entanglement of air and solid, for though either alone may be transparent, their intermixture becomes opaque from the incessant *echoing* of the light.

A simple and effective experiment may be made to illustrate the foregoing Into a little trough with glass slides, pour some water, holding in solution a little bicarbonate of soda. Behind the trough place a light the rays from which pass freely through the liquid, as the continuity is unbroken. Now add a little tartaric acid, which with water also forms a transparent solution ; the acid added to the soda liberates carbonic-acid gas, which, rising in a quantity of minute bubbles, becomes intermingled with the water, breaks up its optical continuity, and instantly converts it into an opaque liquid. If the eye be placed on the other side of the trough, the previously clear liquid will now appear white, like milk. In fact, the whiteness and opacity of milk is due to a precisely similar cause, the myriad of transparent

globules of fat it contains having a different refractive power from the water in which they float.

If, therefore, we strongly squeeze a mass of melting snow, partial liquefaction of the whole will take place, a more ready escape for the air will be afforded, and on releasing the pressure the fragments will be found frozen into a continuous mass of more or less transparent ice. How this re-freezing, or *regelation*, as it is termed, is effected we cannot stay to discuss at this point, for it has been the subject of much controversy; we may return to this question—as it is the most important factor in the formation of a glacier—in a subsequent paper, wherein the explanations that have been given of the river-like motion of a glacier, will also have to be considered.

When, as is sometimes the case, a glacier can be seen from its origin in the snow-fields to its termination in the valley, its resemblance to a river is strikingly manifest. Perhaps, nowhere are these "currents of ice," as Goethe calls them, better seen than at Justedal, in Norway. In that district the Nygaard glacier majestically sweeps down into the valley, the whole of its course being seen at a glance. The writer can never forget the impression this grand spectacle produced upon him as this glacier suddenly burst upon his view. The size of these ice rivers varies considerably. Measuring from their end, or *snout*, to their origin, the glaciers of the Alps are, on an average, from ten to twenty miles long and about half a mile wide. Their depth has been ascertained only approximately; *moulins—i.e.*, cavities in the ice through which the glacier waters escape—have been sounded, and depths from 160 to 350 feet have been found without the bottom having been reached. One of the upper arms of the largest glacier in Switzerland, the Mer de Glace (Fig. 1), breaks off into a vertical wall of ice 140 feet in height. These figures will give some conception of the mass of a glacier. Nevertheless, vast as are these ice streams, they are insignificant compared with the gigantic masses which doubtless covered Northern Europe in a pre-historic time.

That the glacier moves down its rocky bed must have been a fact long familiar to even casual observers. But no accurate knowledge on this subject was possessed till the late Principal Forbes published his "Travels in the Alps" in 1843. By careful measurements, Forbes—and, shortly afterwards, the famous naturalist Agassiz—ascertained not only the average rate at which the glacier moves as a whole, but established the important fact that the centre moves more quickly than the sides. Forbes' determination of the velocity of the different parts of the glacier led him to propound his famous theory of glacier motion which still holds its ground, and to which we shall in another paper return. If a row of stones be laid straight across the glacier to-day, they will not be in the same position to-morrow: supposing it be summer time, the central stones will have crept forward some twenty to thirty inches, the marginal ones but five to ten inches, and the others in proportion. The fact of the speedier motion of the central parts of a glacier had been surmised, a year or two previous to Forbes' measurements, by a Bishop of Savoy, Mgr. Rendu. But long prior to Forbes, in 1788, the celebrated De Saussure made a series of observations on glaciers which led him to suggest that glaciers slid down the valleys, impelled by their own weight. An incident that occurred to De Saussure's party was the means of afterwards revealing, in an unexpected way, the rate of glacier motion. On descending the rocks at the side of the Glacier du Géant—one of the arms of the Mer de Glace—De Saussure left behind him a ladder. Forty-four years later, in 1832, fragments of this ladder were found by Forbes and other travellers at a point much lower down the valley, carried thither by the motion of the glacier. The distance between the two spots having been measured, it was discovered that the part of the glacier where the ladder was imbedded must have descended, on an average, 375 feet each year. Another observer in 1827 had built a hut on one of the Swiss glaciers for the purpose of making observations, and the exact position of this hut was determined when it was erected. In 1841 it was found 4,884 feet lower down the valley, giving an average motion of 349 feet every year.

By the use of surveying instruments and stakes driven in the ice, the *daily* motion of a glacier may be determined. In this manner it has been found that the middle of the Mer de Glace moves through twenty inches a day in summer, but in winter only half as much. In different glaciers the velocity varies according to the size, the inclination, the amount of snow-fall, and other circumstances. "The enormous mass of ice thus gradually and gently moves on, imperceptibly to the casual observer, at the rate of about an inch an hour—the ice of the Col du Géant will take 120 years before it reaches the lower end of the Mer de Glace—but it moves forward with uncontrollable force, before which any obstacles that man could oppose to it yield like straws, and the traces of which are distinctly seen, even on the granite walls of the valley. If, after

a series of wet seasons and an abundant fall of snow on the heights, the base of a glacier advances, not merely does it crush dwelling-houses and break the trunks of powerful trees, but pushes before it the boulder walls which form its terminal moraine without seeming to experience any resistance. A truly magnificent spectacle is this motion, so gentle and so continuous, and yet so powerful and so irresistible." *

The store of energy possessed by a moving glacier enables it to widen and deepen the channel through which it flows. This it accomplishes by the agency of the loose stones entrapped beneath its mass. Thus the glacier acts as a gigantic rasp upon the rocks forming its bed, scratching and grooving their surface, and leaving permanent traces of its course. It is by means of these rock scratchings, or flutings, that geologists have been able to trace the action and indicate the direction taken by ancient glaciers; they have thus proved that the British Isles were once the seat of glaciers far more extensive than those now found in the Alps. †

* Helmholtz: "Popular Lectures," art. "Ice and Glaciers."
† "Science for All," Vol. I., pp. 33–40.

Fig. 1.—The Mer de Glace. *(From a Photograph.)*

On this subject I may quote the following interesting note sent me by my learned friend, the Rev. Maxwell Close, who has largely added to the knowledge possessed by geologists regarding the action of ice in Ireland:—"The glaciation, or ice-abrasion, to which Ireland has been subjected was effected entirely by ice formed upon the present area of the island. But the direction of the ice movement in the north-east of Ireland, and in the northward part of the County Wicklow, seems to have been influenced by the pressure of the ice from what is now Great Britain. There were no centres of ice dispersion on the east side of Ireland. The Wicklow mountains, for instance, instead of giving origin to any flows of the *general* glaciation, were themselves invaded by ice, whose course can be clearly traced backwards for about a hundred miles to the less important hill group of Fermanagh, &c. Some of the centres, or, more properly, areas, of dispersion were ill defined. Others—*e.g.*, that of the Connemara mountains in West Galway —were very distinctly marked. The great ice-flows of Kerry had a compound and not a single origin. As the ice progressed, it not only rounded and scored the rocks by means of the detritus which it

shoved along, but it often left the boulder-clay in long narrow ridges, from thirty to one hundred feet in height, and sometimes one mile in length, which are parallel, not only to each other, but also to the rock-scorings of their district. It is impossible to say what was the greatest depth of the ice; but the ice from the Kerry mountains that crossed the crest of the mountain ridge near Glengariff, which separates Kerry from Cork, has left its scorings on that crest at the height of 2,200 feet. The masses of vein-quartz on the shoulders of Croagh Patrick, at the height of 1,600 feet, retain the scorings done by the ice from the Connemara mountains, fifteen miles distant. Certain mechanical considerations would show that, for the ice to move as it did, its depth must have been very much greater than that indicated by the most elevated of its markings which have been preserved or detected. When the period of the general glaciation of the country had passed, many of the mountain hollows, or corries, had their own small local glaciers, which have often left the strongest evidence that can be imagined of their existence."

We must now return to the striking analogy which is presented by the motion of a glacier and that of a river. When a river flows round a bend, its point of swiftest motion shoots for a time beyond the centre of the stream, regaining its central position if the river continue in a straight course, but swerving to the opposite side if the river-bed turn in the contrary direction. A glacier behaves in a precisely similar manner. Professor Tyndall first drew attention to this fact, proving that the line of swiftest motion in a glacier makes a curve more sinuous than that of the valley itself. Like a river, the glacier is fed by tributaries, bends round a corner, and is retarded by the friction it encounters against its bed, so that it moves more quickly, not only at its centre than its sides, but also at its surface than underneath. Furthermore, the glacier is able to accommodate itself to the size of its channel; forced in heaped-up masses through narrow gorges, it widens and becomes shallower as it passes them, moving swiftly in the gorge, and more sluggishly as the channel widens. The union of several glaciers into one grand trunk stream is strikingly seen in the Mer de Glace, for the sketch of which (Fig. 2), and also for the two following diagrams, we are indebted to a work by Professor Tyndall.*

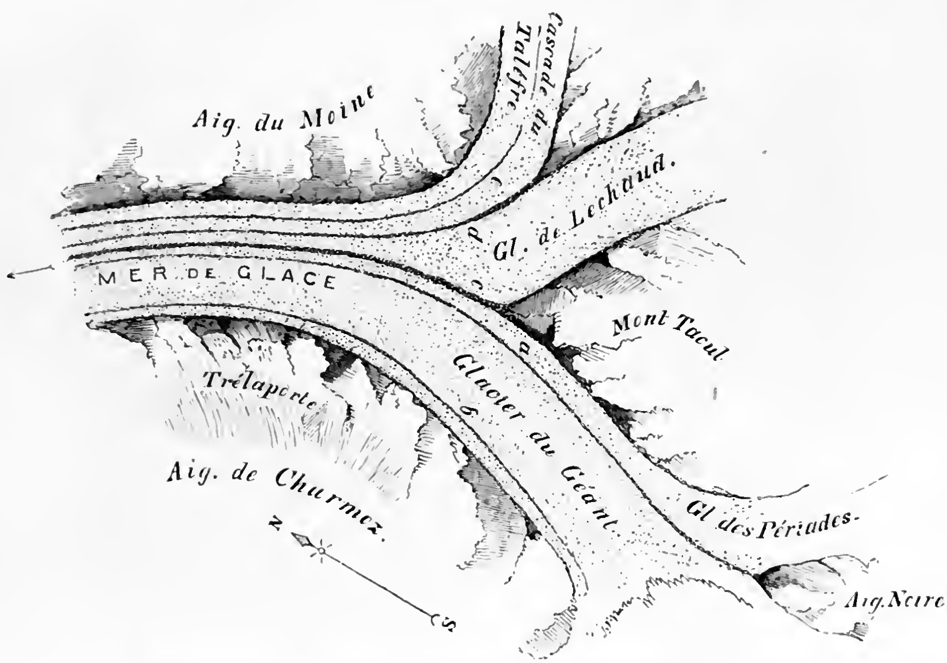

Fig. 2.—Showing the Union of several Glaciers into one great Stream.

The central parts of a glacier being those in most rapid motion, the sides must necessarily be in a state of strain, from the ice being constantly dragged towards the centre. As the ice cannot be stretched to an appreciable amount, the glacier

* "Glaciers of the Alps," p. 367.

breaks at right angles to the line of stretching. Cracks are thus formed, and, opening out by the continual pull, become wider, forming what are known as the *marginal crevasses* (Fig. 3). The arrow indicates the direction of motion of the

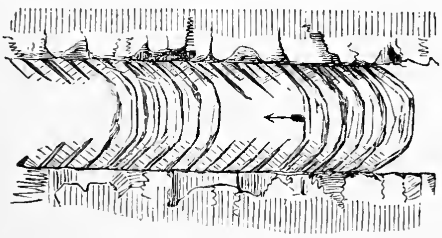

Fig. 3.—Marginal Crevasses.

glacier; the lines on each side, parallel with the barbs of the arrow, indicate the direction of the strain; whilst the darker lines, at right angles to these, show the marginal crevasses. In some places in the drawing the crevasses are seen to stretch right across the glacier; this arises from a sudden change in the inclination of its bed, causing the ice to snap across, and thus forming *transverse crevasses.*

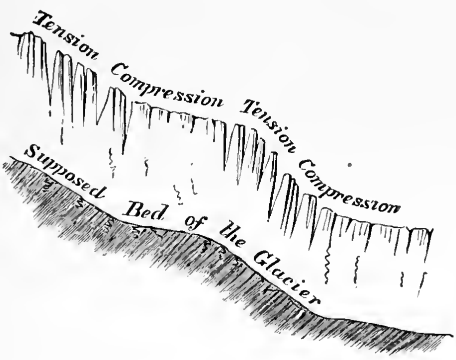

Fig. 4.—Imaginary Section of Glacier in Fig. 3.

The union of these with the marginal crevasses creates in certain places continuous deep fissures, which sweep in great curves across the glacier. It will be noticed that the convex side of the curve points up the valley, making it appear as if the glacier moved more rapidly at its edges than its centre—an anomalous appearance, which much puzzled early observers. But the explanation is now easy: the centre moves more swiftly than the sides, and the crevasses are formed at *right angles* to the line of greatest tension. When a level surface is reached, the pressure from behind forces the broken masses of ice together; they re-unite, and scarcely a trace is left of the gaping transverse chasms. In Fig. 4 is shown an imaginary section of the glacier in Fig. 3, showing the regions of greatest tension and compression.

From a favourable point of view there can be seen, in subdued light, faint streaks across the glacier curving in the direction of its motion. These are the so-called *dirt-bands,* accounted for in different ways, but into the discussion of which we cannot here enter. They are probably formed, at the foot of an ice cascade, by the fine *débris* collecting in the ridges and left exposed after the melting of the snow on the glacier; running, at first, nearly straight across it, the dirt-bands partake of the greater velocity of the central part of the glacier, and hence acquire a curved shape as they are gradually carried down the valley. (See Fig. 2.)

There are other points of interest in the structure of glacier ice, to which we can do no more than allude. One of these is the "laminated" or "veined" structure, which has been accounted for by the pressure to which the glacier is exposed; these less conspicuous appearances are found in regions of greatest pressure, and are thus complementary to the crevasses which occur where the tension is greatest.

But one of the most prominent features of all the glaciers we have not yet mentioned. These are the *moraines,* or masses of stones and *débris* which the glacier bears on its surface or pushes before it. Chiefly through the agency of frost, blocks from the mountain side become detached, and, falling on the glacier, litter its side with scattered fragments of rocks. The edges of a glacier thus become lined with stones, which to some extent prevent the sun from melting the ice beneath them. The consequence is that, as the portions of ice not thus screened melt away, the stony fringe, or moraine, apparently rises to a considerable height, until in some places it is elevated nearly fifty feet above the level of the glacier. When two glaciers unite, one moraine of each joins into a central ridge of stones, called a *medial* moraine, the side ridges being termed *marginal* moraines. The formation of two or more medial moraines is well seen in the diagram of the Mer de Glace (Fig. 2). Pushing far below the limit of perpetual snow, the glacier reaches warm and cultivated regions, where it shrinks in size, and finally abruptly terminates, leaving its rocky burden at its foot; this accumulating from year to year, forms what is known as a *terminal moraine.*

Occasionally, large isolated slabs of stone are found perched on a pillar of ice. These are the so-called *glacier-tables,* the formation of which is simply due to the stone screening the ice beneath it from the action

of the sun: hence, whilst the surrounding portion of the ice melts, the part beneath the slab of stone is protected, and thus appears to rise from the general level of the glacier. It is really the glacier which has sunk by the melting of its surface, and the erratic position of the perched stone indicates the former level of the glacier. One unusually large glacier-table on the Mer de Glace was measured, and found to be a slab twenty-three feet long, resting on a pillar of ice thirteen feet high. The larger the stone, the higher it will tend to rise, as a greater surface of ice is protected from the sun's rays. The slabs of stone usually "dip" towards the south, owing to the direction of the solar rays, which warm the surface of the stone unequally; by degrees the inclination given to the slab is so great that it falls off, the uncovered ice-pillar now melts away, and a new one hard by rises in its stead.

Another curious feature is more rarely met with on the surface of the glacier. These are the *gravel-cones*, for which the lower glacier of the Aar is remarkable. These cones sometimes reach a height of twelve feet, and a circumference of forty feet at the base. They present a singularly artificial appearance, from their geometrical figure, and their aspect so dark and foreign to that of the pure ice around. Gravel or sand forms, however, only the exterior of the cones; within, they are solid ice. Their formation has been explained in a somewhat similar way to that of the glacier-tables. The streams of water from the melting surface of the glacier carry with them sand and gravel from the medial moraines; the course of the stream is soon checked by a crevasse or hole in the glacier in which its waters are engulphed, forming a noisy cascade or *moulin*. The sand and gravel, borne by the stream, are thus precipitated into the heart of the glacier, but in process of time, as the glacier melts away and the stream shifts its course, the gravel once more appears on the surface. Here the protecting influence it exerts on the ice comes into play, and the mass of gravel rises, a cone being formed like that in an hour-glass, whose declivity is the measure of the friction between the sandy particles and the ice.

Not only does the sun melt the upper surface of the glacier; the natural heat of the earth melts the under-surface to some extent, but whether the liquefaction goes on above or below, the water formed ultimately issues from the foot of the glacier, in summer as a turbid torrent laden with the rocky dust the glacier has ground in its course.

Thus the glacier is ever in process of dissolution at its lower extremity and of renewal at its upper. Its *substance* is fleeting, but its *form* is permanent; and this permanence of form depends upon the permanence of the conditions that surround it. If those change, *it* changes, and a new form results. Hence the life-history of the glacier is not unlike that of an animal or of a species. These have their youth, their manhood, their decay, and their death; and, like the glacier, they present a permanence of form under a ceaseless flux of material. And so, too, we ourselves may be said to resemble a glacier: whilst the material of our bodies is ever being renewed, our consciousness, our personality, the imperishable form within, remain unchanged.

DIAMONDS.

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LOVE of personal decoration may be fairly counted one of the most widely spread of human passions. "The first spiritual want of a barbarous man," says Mr. Carlyle, "is decoration." * Such a want was unquestionably felt by the people of our own islands long before Britain began to figure in history; in times, indeed, far older than the oldest of our written records. Relics of the primitive ornaments which were roughly fashioned in pre-historic or in non historic times are occasionally brought to light by the antiquary while exploring those ancient barrows, or earth-mounds, in which our rude forefathers sleep. There the spade is likely enough to turn up the amber bead, or the ornament of jet, or the bronze pin, or, may be, simply a perforated tooth or bone or shell; yet all testifying to the vast antiquity of this practice of personal adornment. And just as no age seems to have been too remote, so no people seem to be too low to indulge in this practice; as we trace it backwards to the pre historic past, so we trace it downwards to the most

* "Sartor Resartus," chap. v.

uncivilised of peoples in these latter days. Clothing may be entirely absent, even the barest necessities of life may be scant, but nevertheless the savage will make some crude attempt at decoration. It would be hard to depict a more abject people, for instance, than the Tasmanians—a hapless race who have rapidly died out before the advance of the white man. And yet the poor Tasmanian would collect the prettiest of shells to be found in the island; would patiently clean them, so as to expose their pearly sheen and rainbow hues; and would then string these glittering ornaments into a necklace, which —to judge from specimens preserved in our museums—would hardly have disgraced her fair-skinned sisters in more favoured lands.

Shells and other animal products—notably pearl and coral—still obtain as materials for personal decoration among nations of the highest culture. But in seeking the most appropriate objects for such purpose, the choice among civilised peoples has generally fallen upon those mineral substances which are not only sufficiently beautiful to be prized for brilliancy and for colour, but at the same time are sufficiently hard to be durable and to receive a high degree of polish which is not easily lost by wear. If the stone be also one of rare occurrence, it becomes of course still more precious. The three-fold combination of brilliancy, hardness, and rarity is nowhere more conspicuous than in the *Diamond;* and hence the diamond has long taken rank among the most highly-prized of our precious stones.

No less keen an observer than Shakspere has told us that—

> "Dumb jewels often in their silent kind"

are able to effect "more than quick words." * It is the purpose of this article to put a tongue into some of these "dumb jewels," and to listen to their scientific teachings. We shall thus endeavour to add instruction to their fascination, to show that there is something in them worth noting beyond mere beauty and glitter; to reveal, in short, their chemical and physical history. It is with only one stone, however, that we purpose at present dealing; and as the most typical example of a precious stone we naturally select the diamond.

One of the most attractive objects in the Paris Exhibition of 1878 was the collection of national jewels; and undoubtedly the most attractive object in this collection was the famous Regent or Orleans Diamond. Among historical diamonds this stone is in many ways unrivalled, and may therefore fitly form the text of this article. A few other diamonds, it is true, may exceed it in weight; but assuredly none can surpass it in brilliancy of lustre, in purity of water, or in perfection of form.

The Regent is an East Indian stone which was found in one of the famous diamond-mines near Golconda. It has often been styled the *Pitt Diamond,* in allusion to its having at one time been in the possession of Thomas Pitt, the grandfather of the first Earl of Chatham, when Governor of Fort St. George. This was the diamond to which Pope pointed in his libellous lines:—

> "Asleep and naked as the Indian lay,
> The honest factor stole the gem away." †

The name of Pitt is now, however, but rarely heard of in association with this stone; and it is usually described either as the *Orleans* or as the *Regent Diamond*—names which refer to its having been acquired for Louis XV. by the Duke of Orleans, when Regent of France, at the solicitation of John Law, the famous financial schemer. It is needless, however, to occupy space better devoted to scientific details by recalling the curious history of this stone.

A good notion of the size and the shape of the Regent may be obtained from Fig. 1. Its elegant form, encircled by a multitude of facets, is of course the result of art, the stone having been cut by skilful craftsmen into the shape best fitted to display its beauty. But a diamond in its rough state, just as it is taken from its resting-place in a bed of gravel,

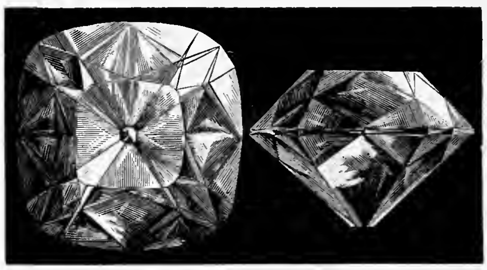

Fig. 1.—The Regent Diamond. (*Natural Size.*)

is far from being a formless mass. Its native shape, however, is widely different from the shape of most cut stones. By far the greater number of mineral substances, and not a few artificial products, are capable, under favourable conditions, of assuming definite shapes, always symmetrical and often extremely beautiful. Water, for instance, when allowed slowly to freeze into a mass of rigid ice, exhibits this tendency. Instead of solidifying into a formless mass, it tends to branch out into

* "The Two Gentlemen of Verona," Act iii., sc. 1.

† "The Man of Ross."

graceful shapes, which often mimic the spreading frond of a fern. Who, indeed, has not admired upon his bed-room window those beautiful

> "Ice ferns on January panes
> Made by a breath?" *

This power of solidifying in regular shapes is known as *crystallisation.* It is not, however, every kind of matter that enjoys this power. Take, for instance, a piece of glass, and mark how different its structure from that of ice; observe, in fact, the difference between the "January pane" and the "ice ferns" which cling to that pane. Sufficient heat will fuse the glass to a clear liquid; but when this liquid cools, it solidifies without any tendency to shoot out in one direction rather than in another. It is true that, under exceptional conditions, glass may be induced to crystallise; but then its characters are so greatly changed that the glass loses its glassiness, and is hence said to be *devitrified.* Under all ordinary conditions, the mass of glass is without regular form. Some kind of shape of course it must possess, like every other solid body; but it is an irregular or accidental shape, lacking all symmetry and definiteness; so far, indeed, from being anything like a crystal, it is more like

> "That other shape,
> If shape it may be called, which shape had none." †

Bodies which are thus destitute of definite form, save that which is given to them from without, are said to be *amorphous;* while those which are capable of spontaneously assuming regular form are described either as *crystallised* or as *crystalline,* according as the shape is well marked or merely confused: thus sugar-candy is crystallised, and loaf-sugar crystalline. The diamond is generally found in well-defined, symmetrically-shaped, solid forms, or *crystals,* of which one of the most common is that represented in Fig. 2.

And here we may remark that it is not a little curious to trace this word "crystal" to its source. Originally we find it applied to that clear and hard substance which is still known as *rock-crystal*—a mineral which was formerly used to a large extent in jewellery, but which is now chiefly employed in the manufacture of spectacle-lenses, when it is termed "pebble." This mineral was found by the ancients in the clefts of those granitic rocks which rise into sharp peaks high above the snow-line in the Alps. So clear, so ice like were these crystals, that it seemed fair enough to assume that they were nothing but intensely frozen water: an assumption which was fortified by their frequent discovery in the neighbourhood of Alpine glaciers. And thus it came to pass that the Greek word for ice—*crystallos*—was applied to this substance.

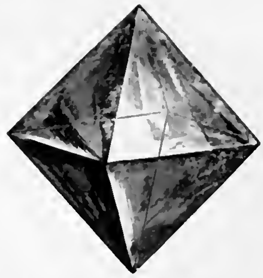

Fig. 2.—A Regular Octahedron; a typical Form of the Diamond.

That this view of the origin of rock-crystal was seriously held by the philosophers of antiquity is clear from a passage in Pliny, where we are told that this crystal "is found only where the snows of winter freeze hardest; it is certain that it is ice, whence also the Greeks gave it the name." ‡ Nor is there the slightest doubt that he refers here to rock-crystal, for a little farther on he confesses that "it is not easy to say why it is born with six angles and six faces." This description of the six-sided forms agrees exactly with the common crystalline characters of rock-crystal, as shown in Fig. 3.

In modern times the term "crystal" has received very extended use, and is now applied to all regularly-formed solids, however widely they may differ from the forms which rock-crystal assumes. In other directions, too, the term has attained even wider significance. Thus, a Frenchman speaks of flint-glass as *cristal*—an application of the word which has evidently been suggested by the beautiful limpidity and brilliancy of such glass, and by its resemblance in these respects to the purest forms of rock-crystal. Yet it is well to note the laxity with which the term is here used; for the glass which is thus called "crystal" is just one of those substances that, as explained above, are eminently uncrystallisable. If the flint-glass presents any definite shape, it is a shape impressed upon it from without, not developed from within. A short time ago a beautiful kind of paper-weight was introduced, which consisted of a block of clear colourless flint glass, cut into various geometrical

Fig. 3.—Rock Crystal; occasionally mistaken for Diamond.

* Tennyson's "Aylmer's Field." † "Paradise Lost." ‡ "Hist. Nat.," xxxvii. 9.

forms identical with those of natural crystals. But these solids, after all, had only the barest semblance to a crystal: they were, in fact, produced by art operating on the exterior, while a true crystal is formed spontaneously by the natural outgrowth of the substance.

Up to within about a century ago, the diamond was regarded as simply a peculiar kind of rock-crystal; nor indeed is the difference always understood even at the present day. It has occasionally happened that an emigrant has thus been bitterly deceived, after having travelled, it may be, thousands of miles, with his supposed treasures. Ignorant of minerals, he has counted himself fortunate in having picked up, in the bed of a stream in some unknown land, a number of beautiful little crystals which are as clear as the purest drops of water; if he looks at them carefully, he observes that every edge is as sharp and every face as smooth as though it had been cut by the most skilful of lapidaries; moreover, if he touches these faces with a hard steel file, he fails to make the slightest impression upon them. What, then, can such stones be but diamonds?

The most superficial comparison of the crystalline forms of the diamond with those of rock-crystal is sufficient, however, to set all doubt at rest. It is true that both the rock-crystal and the diamond present symmetrical shapes, but the kind of symmetry is very different in the two cases. Look at the rock-crystal in Fig. 3, and observe that the column has six sides to it, and that the cap has also six sides. Now turn to the crystal of diamond in Fig. 2, and mark the difference: here is a solid, made

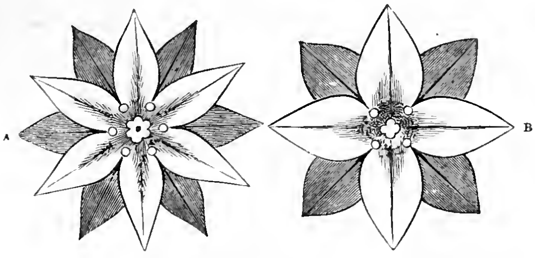

Fig. 4.—Diagrammatic Plans of Flowers, showing in (A) six-sided, and in (B) four-sided symmetry.

up of an upper and a lower half, each bounded by four faces, but showing nothing like the six-sidedness of the rock-crystal. The two crystals are, in fact, as different in their symmetry as the two flowers diagrammatically represented in Fig. 4. In A the floral leaves and other parts are arranged in sixes: this therefore corresponds with the arrangement of the faces in the rock-crystal, where everything is repeated around the centre six times. In B the parts of the flower are disposed in fours: this therefore agrees in symmetry with the diamond, where the faces are grouped around the centre in sets of four or multiples of four.

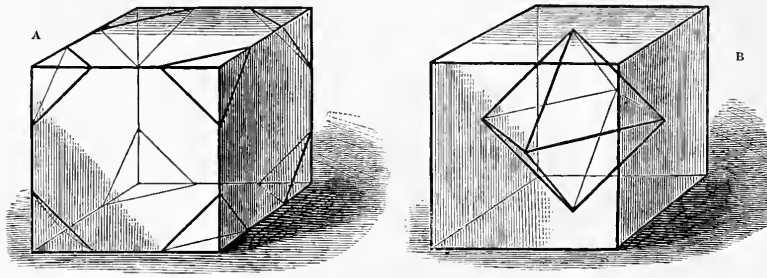

Fig. 5.—Cube with its solid Angles cut off in A, and with an "inscribed" Octahedron in B.

The typical crystal of diamond, represented in Fig. 2, has eight faces—four above and four below—and is therefore called an *octahedron*. But there are many other solids which also have each eight faces, and are hence equally entitled to be called octahedra. To distinguish the diamond-form, however, it is only necessary to observe that each of its eight faces is a triangle, having the three sides equal: these eight equilateral triangles make up what is called, for distinction's sake, a *regular octahedron*. It is not difficult to obtain such an octahedron from a common die or cube. If each of the eight corners of a cube be properly cut off, as in Fig. 5 (A), eight little pyramids will be obtained, and there will be left behind a perfect regular octahedron (B). It is in consequence of this close relationship between the octahedron and the cube, that the student of crystals speaks of the diamond as crystallising in the *cubic system*, although the cube itself is not a characteristic form of this stone.

It must not be supposed that every crystal of diamond is as simple as that represented in Fig. 2, which we have hitherto taken as our type. The forms which the diamond assumes are indeed very various, and often exceedingly complex, but these forms are all governed by the same law of symmetry, and are all related more or less closely to the cube. They belong, in fact, to one common group or system. Fig. 6 represents some of these characteristic forms of diamond. It should be noted, however, that the faces are frequently curved.

Whatever form the diamond happens to possess in its native state, it may always be split with ease into an octahedral shape, like that represented in Fig. 2. This property of splitting in a definite direction is known as *cleavage*, and is a property enjoyed by most crystallised substances. If a body be uncrystallised, such as a piece of glass, it exhibits no tendency to split in one direction rather than in another; but if it be crystallised the case is very different, for the effect of a blow is then, not to shiver it into irregular fragments, but to split it along definite planes. The diamond possesses an octahedral cleavage; that is to say, it splits along planes which correspond to the faces of a regular octahedron.

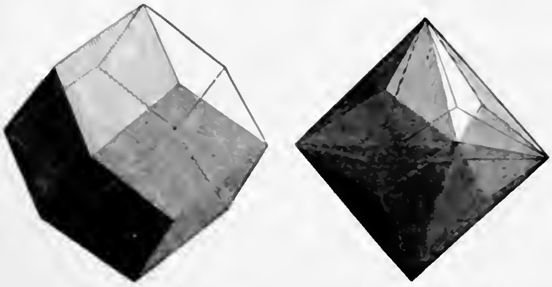

Fig. 6.—Typical Forms of Crystals of Diamonds.

This property of cleavage is taken advantage of by the diamond-cutter in the preparatory operation of dressing a diamond. If the rough stone be not already in the form of an octahedron, it can be readily reduced to that form by skilfully delivered blows. Or if it be desired to remove a flaw or other imperfection in the stone, the diamond-splitter can detach a slice by a single tap. The experienced eye readily traces the direction in which a fragment may be split off with ease, rapidity, and certainty. To effect this operation, the diamond-splitter—who is represented at work in Fig. 7—imbeds the stone in warm cement, composed of a mixture of resin and brick-dust, and attached to the end of a small wooden rod. Part of the stone is free, and on this part the operator traces, by means of another diamond, the direction in which he intends to effect the cleavage. Then, supporting the rod of wood in an upright position, by insertion in a hole in a block of lead, he places a steel blade in the notch which has been cut by the second diamond, and strikes a sharp blow on the back of the blade by means of a little hammer, which is really a peculiarly-shaped steel rod. The stone, having been split by a smart tap, is released from its matrix by warming the cement, and is then ready for cleavage in another direction.

After having been duly cleaved, the diamond passes to the hands of the cutter, who skilfully trims it to the shape which it is required to display. This operator imbeds the greater part of the stone in cement carried at the end of a wooden handle, and then rubs the exposed part against another

Fig. 7.—Splitting a Diamond.

Fig. 8.—Cutting a Diamond.

diamond similarly mounted. In Fig. 8 the cutter is seen patiently rubbing the two stones together until the surfaces are sufficiently worn down. His hands, it will be observed, are protected by thick leather gloves. The operation is performed over a small box, which catches the dust, this diamond-dust being of such value for polishing purposes that every grain is carefully preserved.

It is worth noting the successive stages by which the "cutter"—or, as he might more appropriately be called, the "rubber"—is able to develop the form best adapted to display the beauty of the diamond. Let us see, for example, how he could cut the Regent out of an octahedron; how, in short, Fig. 2 could be converted into Fig. 1. The first step is to grind down one of the four-sided points, or solid angles, to a flat surface, which is called the *table* of the diamond. Thus, if A in Fig. 9 represent a side elevation of an octahedron, the summit will be replaced by a plane, as shown in B. Then the opposite four-sided point is similarly rubbed down; but this second plane, which is known as the *collet*, is much smaller than the table, as indicated in B. The line which runs horizontally round the stone, between the table above and the collet below, is termed the *girdle*: evidently it is the natural edge of the octahedron separating the upper from the lower four-sided pyramid.

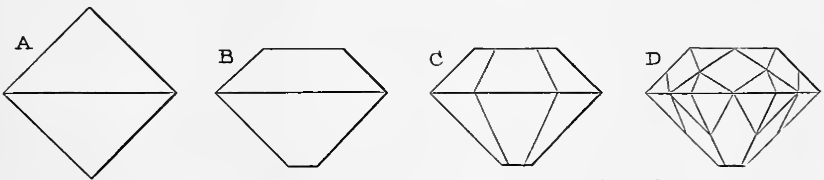

Fig. 9.—Successive Stages in cutting a Brilliant from an Octahedron.

Having thus given a general shape to the stone, it remains to cut the surface into *facets*; some lozenge-shaped and others triangular. In C these facets are in course of formation, and in D they are completed. The shape thus ultimately given to the cut diamond is known as the *brilliant*; and the parts of the stone below the collet and the girdle are distinguished as the *pavilions*, while the parts between the table and the girdle are sometimes termed *bezils*. In order to bring out the beauty of the diamond to greater advantage, it is necessary to preserve certain proportions between the several parts of the stone. The Regent is especially notable for the correctness of these proportions, and is probably the most perfect brilliant ever cut. It weighs in its present state $136\frac{3}{4}$ carats. If the proper proportions are not duly respected, the stone lacks brilliancy; and this, unfortunately, is the case with the famous Koh-i-noor. After it had been exhibited in the Great Exhibition of 1851, it was cut by Herr Voorsanger, a workman sent over to this country for the purpose by Messrs. Coster, the famous diamond-cutters of Amsterdam. The great object was to reduce the irregularly-shaped Indian-cut stone to symmetrical form with as little loss of weight as possible. As a consequence of this economy, the stone is much too broad for its depth, and therefore is sadly wanting in brilliancy. Fig. 10 shows the Koh-i-noor in its present form, which is that of a thin or "spread" brilliant. Its weight is now $102\frac{1}{2}$ carats, the loss during re-cutting having been $83\frac{9}{16}$ carats.

It is not every diamond that is adapted by its natural shape to be cut into the form of a brilliant; and stones which could not be so cut without great loss of weight are generally wrought into the form known as a *Rose*. From Fig. 11 it will be seen that the rose has a flat base, and is domed above, the dome being cut into two rows of facets, the number of which varies, however, in different varieties of the rose.

After the diamond has been cut into the form of either rose or brilliant, it requires to be polished in order to develop that lustre and fire which form so prominent a feature in the beauty of the diamond. To impart polish, the cut stone is imbedded in a

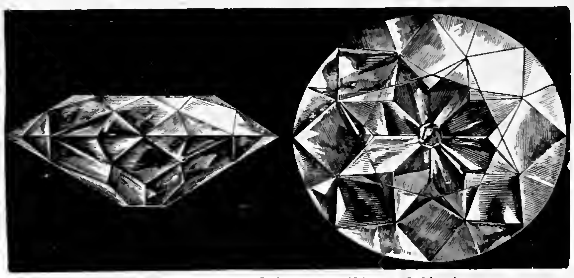
Fig. 10.—The Koh-i-noor. (*Natural Size.*)

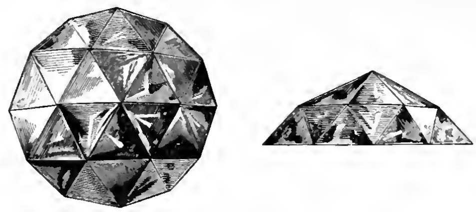
Fig. 11.—A Rose-cut Diamond.

fusible metal, like solder, contained in a copper cup which is furnished with a wooden or metal handle. The diamond is fixed in the matrix by hand, and the soft metal when warm is worked into a conical form, having at its apex the exposed face of the diamond which is to be polished. When carefully mounted in this fashion, it is handed over to the polisher, who places the exposed face on a circular disc of iron mounted on a vertical axle, and rapidly rotating in a horizontal plane. The wheel is covered with diamond-dust, moistened with oil, and a number of diamonds may be placed on the same wheel at the same time. The polisher is represented at work in Fig. 12.

In cutting, or rather rubbing, the diamond into shape, and in polishing the cut stone, no abrading agent can be used except the diamond itself. It is this supreme hardness that gives much of the value to the diamond; for the roughest wear scarcely destroys the sharpness of the cut edges or deadens

Fig. 12.—Polishing a Diamond.

its polish. This exceptional hardness of the diamond is well known, and gives point to the expression "diamond cut diamond;" but the popular notion often credits this gem with an indomitable nature which it can scarcely claim. Among the many extravagant things which Pliny tells us is his remark that certain diamonds have such excessive hardness that when struck upon an iron anvil the hammer and anvil are torn asunder. Yet he coolly asserts that such stones can be subdued by digestion in goat's blood, provided that the curious solvent be fresh and warm. Without going to this height of extravagance, many believe, even nowadays, that a true diamond will resist the blow of a hammer. This popular error arises from confounding hardness with toughness—two physical properties which are entirely distinct. A piece of gutta-percha, for example, is so tough that it is torn asunder with difficulty, yet so soft that it may be indented by the finger-nail. On the other hand, the diamond is so hard that no other substance is capable of scratching it, yet so brittle, that the Regent itself might be shattered into fragments by dropping it on to the ground from the height of only a few feet.

Every one knows that the prime object in polishing a diamond is to develop its lustre with due effect. This remarkable lustre is the result of the high power which the stone possesses of reflecting, refracting, and dispersing—that is, of shedding forth, bending, and decomposing—the light which falls upon its surfaces. To attempt, however, a full explanation of the action of the diamond upon light would need a special article. It is sufficient here to remark that the high refracting power of the diamond led Sir Isaac Newton to his famous conjecture that this gem might be "an unctuous substance coagulated."

This sagacious inference was confirmed by a remarkable experiment conducted in 1695 by some members of the Florentine Accademia del Cimento. In the presence of the Grand Duke Cosmo III., they subjected a diamond to the heat of the sun concentrated by a large burning-glass, when they found that the hard, indomitable gem quietly vanished into thin air. It should be noted, however, that Robert Boyle—one of our earliest experimental philosophers, who has been facetiously described as "the father of modern chemistry, and the brother of the Earl of Cork"—had previously found that a diamond exposed to a high temperature is partly dissipated in "acrid vapours." The true explanation of such phenomena was reserved for the great French chemist Lavoisier, who not only burnt the diamond but examined the product of its combustion. A diamond was imprisoned in a glass vessel containing air, and standing over mercury; by means of a burning-glass it was then ignited, and the resulting vapour, being confined in the vessel, was subjected to chemical scrutiny. This vapour was found to be neither more nor less than carbonic-acid gas—a gas which consists of carbon and of oxygen, and is produced whenever charcoal or any other form of carbon is burnt, either in pure oxygen or in atmospheric air.*

* Vol. I., p. 356.

Here, then, was a novel and unexpected discovery. If the diamond produced during its combustion nothing but carbonic-acid gas, it is clear that it must consist of pure carbon; in other words, it is closely related chemically to such familiar and widely dissimilar substances as charcoal, coke, and black-lead, and would indeed be chemically identical with these substances provided that they existed in a state of perfect purity.

To burn diamonds may be an expensive, but it is by no means a difficult, experiment. Even the heat of a mouth blow-pipe is sufficient to ignite the gem. The experiment may, however, be more conveniently performed in an apparatus such as that represented in Fig. 13. Here is a glass vessel containing oxygen gas, and having at the bottom a small

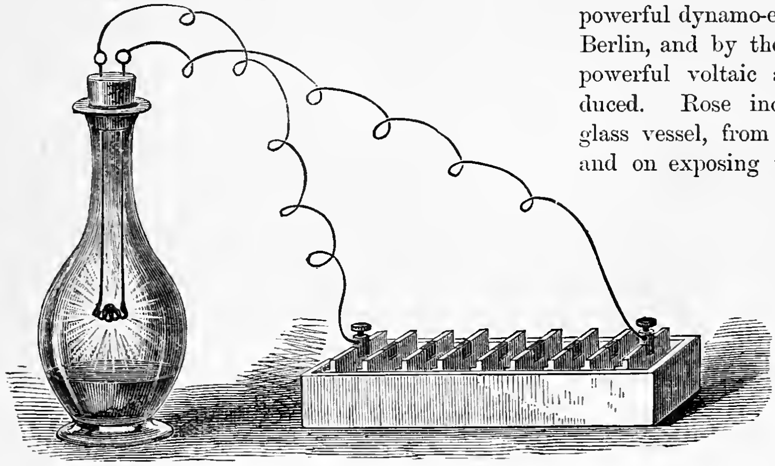

Fig. 13.—Burning a Diamond in Oxygen.

quantity of limpid lime-water. The diamond is placed in a spiral of fine platinum wire, or in a little boat of thin platinum foil, and a current of electricity from a small galvanic battery is sent through the platinum. The metal offers a resistance to the passage of the electricity, and immediately becomes incandescent. This heat is then communicated to the diamond, and as soon as the gem is kindled the circuit is interrupted, and the platinum consequently ceases to glow. But the combustion of the diamond, once started, steadily continues: the carbon combines with the oxygen, forming carbonic-acid gas, and the action is sufficiently energetic to maintain the diamond at a vivid glow. The combustion over, the lime-water may be shaken up, when it immediately becomes milky, in consequence of the formation of an insoluble carbonate of calcium, which remains suspended in the turbid liquid.*

* This test for carbonic acid has been fully explained in Vol. I., p. 356.

It is worth noting that after a diamond has been strongly heated in air the half-burnt surface exhibits curious triangular impressions, such as those seen in Fig. 14. If, on the other hand, the diamond be strongly heated without access of air, its surface becomes blackened. Some interesting experiments on this subject were made by Gustav Rose, a very eminent chemist in Berlin, a short time before his death in 1873. Dr. Siemens had erected a powerful dynamo-electric machine at his works in Berlin, and by the action of this machine a very powerful voltaic arc, or electric light, was produced. Rose inclosed a diamond in a strong glass vessel, from which air had been exhausted, and on exposing the gem to the intense heat of the arc its surface became encrusted with a thin layer of a graphitic substance, like the so-called black-lead of our pencils. Indeed, the chemist knows that plumbago or graphite is only another form of the protean element carbon.

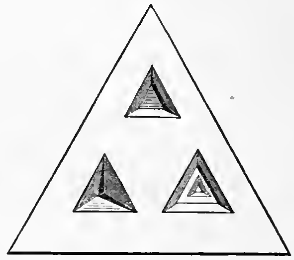

Fig. 14.—Face of an Octahedron of Diamond, showing Triangular Impressions developed by Heat.

After the combustion of the diamond, a small quantity of ash generally remains behind. This ash has been made the subject of careful microscopic examination by several eminent observers. Petzhold asserted that he could detect in this ash a cellular structure, indicating the vegetable origin of the diamond; and Göppert, who had given much attention to such subjects, was inclined to the same belief. The evidence, however, does not appear sufficiently strong to warrant any assertion as to the organic origin of the gem, although evidence of a different nature might be cited to show the probability of such an origin. In fact, the genesis of the diamond, after all that has been said on the subject, remains one of the unsolved enigmas of science.

Interesting as it might be to trace the geographical distribution of the diamond, and to study the geological conditions under which it occurs, any excursion in that direction is forbidden by the limits of this article. It was explained, indeed, at the outset, that our popular study of the diamond would relate to its physical and chemical

history; and to that history we have strictly confined ourselves.

From what has been here advanced with respect to the crystalline form and the chemical composition of the diamond, we may learn one of the great differences between a scientific and an unscientific view of a subject. The man of science, in looking on the world around him, detects differences where the uneducated eye sees only resemblances, while he traces resemblances where the unscientific observer recognises nothing but difference. This general proposition has been strikingly illustrated in the course of our present study. Thus we have found that the inexperienced eye may fail to detect any difference between a rough diamond and a piece of rock-crystal; but the observer who has only the slenderest acquaintance with crystal-forms recognises at once a vast difference between the two substances. On the other hand, an unscientific observer, looking only at superficial characteristics, refuses to admit any similarity or kinship between a diamond and a piece of charcoal or a piece of black-lead; yet the student who has learnt only the veriest rudiments of chemistry recognises the intimate relationship that unquestionably exists between these several forms of matter. Surely it is no mean triumph of the chemist to have shown that a sparkling, priceless gem like the Regent diamond is identical in essence with the black-lead which the housemaid uses for polishing a stove, and is well-nigh identical with the coke and charcoal, with the anthracite, and with other carbonaceous fuels, which are every day being thrown by the ton into our furnaces.

THE HISTORY OF A HEN'S EGG.

By Thomas Dunman,

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AMONGST the numerous natural objects with which we are daily brought into contact, none is, perhaps, more generally familiar than the egg of the common fowl; nor can there well be found a study more replete with interest and instruction than the history of its origin and of the wonderful changes by which, during the process of hatching, it becomes converted into a chick. To place our readers in possession of a few of the more important stages in this wonderful history is our object in the present paper.

Before considering the manner in which the egg is first formed in the body of the hen, it will be well to notice briefly the structure of the egg as we ordinarily find it when just laid. First, then, we have to notice in the new-laid egg that it is invested by an outer porous covering, the *shell*, composed of salts of lime deposited in an organic basis. Upon examination, the shell will be found to be lined with a toughish, opaque membrane, the *shell-membrane.* In perfectly fresh eggs this shell-membrane appears to consist of only a single layer, but close examination shows that it is really composed of two; a fact which is easily ascertained in an egg which has been kept for a few days, as the two layers of membrane tend to separate from each other at the broad end of the egg, and to develop between them a small cavity, into which air passes, and which is termed the *air-chamber* (*a ch*, Fig. 1). As this air-chamber, when present, is easily visible when an egg is held up to the light, it forms a ready means by which the careful housewife may test the freshness of the eggs with which she is supplied. The development of this air-chamber is due to the shrinkage of the albumen or white of the egg, consequent upon its evaporation through the porous shell.

Next to the shell-membrane we come upon the white of the egg, or, as it is technically termed, the *albumen.* This material is of two kinds, one rather more fluid than the other. A layer of the more fluid kind lies next to the shell-membrane, and a similar layer invests the yolk. Between these two layers the albumen is made up of the less fluid material, which consists of a kind of fibrous network, the meshes of which contain fluid.

Extending from the yolk on either side nearly to the shell-membrane are to be seen, in the albumen, two opaque, somewhat woolly-looking twisted cords. These, when examined with a lens, appear to consist of opaque white knots banded together, and have consequently received the somewhat fanciful name of *chalazæ*, or hailstones.* The use of these chalazæ is probably to act as elastic pads to keep the yolk in position.

* Greek, *chalaza*, hail.

Turning to the yolk, we find it consists of a mass of yellow material inclosed in a very thin and delicate membrane, which is easily creased, and which is termed the *vitelline*, or *yolk-membrane.** The yolk itself is made up entirely of cells, of which there are two kinds, one lighter in colour than the other. These lighter-coloured cells constitute the so-called *white yolk*, while the others form the *yellow yolk*. By far the larger portion of the yolk is composed of the latter, through which the white yolk is disposed in the manner shown in our diagram (Fig. 1). First, immediately beneath the yolk-membrane there is a thin layer of white yolk, and this is connected with a somewhat flask-shaped mass of the same material occupying the centre of the general body of the yolk, while several thin layers of white yolk are arranged through the mass

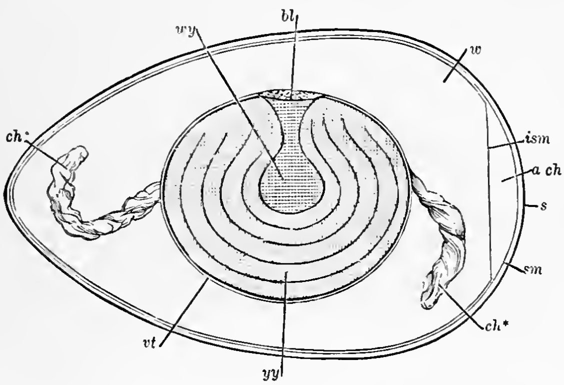


Fig. 1.—Diagrammatic Section of a Fowl's Egg.

(bl) Blastoderm; (wy) White Yolk; (yy) Yellow Yolk; (vt) Vitelline Membrane; (w) Albumen; (ch) Chalazæ; (a ch) Air-chamber; (ism) Internal Layer of Shell Membrane; (sm) External Layer of Shell Membrane; (s) Shell.

concentric with the external layer. Resting on the yolk, immediately beneath the yolk-membrane, will be seen a small, whitish, disc-like body, about one-eighth of an inch across. If this be examined with a lens, it will be seen to exhibit two more or less well-defined parts—an outer white ring, and an inner transparent circular space, in which dots of white are usually seen (Fig. 2). This disc is the so-called *blastoderm.*† From it, and *from it alone*, the future chick will be developed, the remainder of the yolk serving only as nutriment for the chick until hatched. The central clear space is called the *pellucid area*, the outer white ring the *opaque area*. It is in the pellucid area that the chick is developed, the opaque area giving rise to certain temporary structures, which serve a purpose ending with the hatching of the egg. As shown in the diagram (Fig. 1), the blastoderm rests upon the top of the flask-shaped mass of white yolk, between which and its lower side is a small cavity filled with clear fluid, in which a few cells may be seen floating. The blastoderm itself consists at this period of two layers of cells, and the upper layer, extending beyond the edges of the lower one, rests directly upon the white yolk, and gives rise to the opaque area.

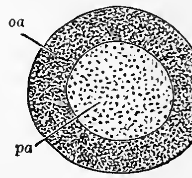


Fig. 2.—Blastoderm as seen from Above.

(oa) Opaque Area; (pa) Pellucid Area.

These are the structures present in the hen's egg when laid; but in order to thoroughly comprehend their history and relative importance we must go back to a much earlier stage, and trace their formation in the body of the hen.

As every one knows who has ever prepared a fowl for cooking, there is always found in the body of a laying hen a structure commonly known as the "egg-bag," which contains several small yellow spherical bodies, inclosed in delicate capsules. Each of these yellow spheres resembles the yolk of an egg in being composed of yellow and white yolk-cells, and also in being inclosed in a delicate yolk-membrane. Each of these spheres is a so-called *ovum*, or egg proper, and is found to contain a small disc, the *germinal disc*, inside which is a small bladder-like body, which is the *germinal vesicle*, while inside this again is a small spot, the *germinal spot* (Fig. 3).

When the ovum is quite ripe, the capsule bursts, and it is discharged into a long tube with muscular walls, which is termed the *oviduct*. In this tube the accessory structures are added to the ovum so as to convert it into the egg ready for laying. In the upper portion of the oviduct the white of the egg is deposited round the yolk; next the chalazæ are formed. A little lower down, the shell-membrane is deposited, and lower still the shell is formed by the pouring out of a thick white fluid in which mineral matter is deposited. After this last process, which takes some twelve or eighteen hours, the egg is passed with its narrow end downwards to the exterior, and is, as we say, *laid*.

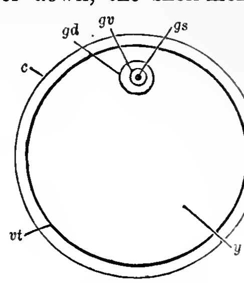


Fig. 3.—Ovum in Capsule of Ovary.

(c) Capsule; (vt) Vitelline Membrane; (y) Yolk; (gd) Germinal Disc; (gv) Germinal Vesicle; (gs) Germinal Spot.

These are, however, by no means the only changes which take place in the ovum during its

* Latin, *vitellus*, yolk. † Greek, *blastos*, a germ; and *derma*, a skin.

passage down the oviduct. As soon as the ovum enters the oviduct the germinal vesicle and germinal spot disappear. At the same time, remarkable changes take place in the germinal disc. First a furrow makes its appearance, crossing the disc and dividing it into two; this is followed by a second furrow at right angles to the first, and so the disc becomes divided into four segments. These primary furrows are very speedily followed by others, some passing like radii from the centre to the circumference, others crossing these, and so cutting the germinal disc into a number of small segments, each of which constitutes a *cell* (Fig. 4, A B C). A somewhat similar process goes on beneath the surface of the disc, and eventually there is produced from it the blastoderm, with its two layers, such as we find it in the laid egg.

It will be observed that the blastoderm, which, as we have already said, is the only part of the egg which is developed into the chick, is produced by the method just described from a single cell. This cell, like all other cells, is composed of that substance known as *protoplasm*, which is present as an essential constituent in all living beings. The process of splitting up, by which the germinal disc becomes converted into the blastoderm, with its upper and lower cellular layers, is known as *segmentation*.

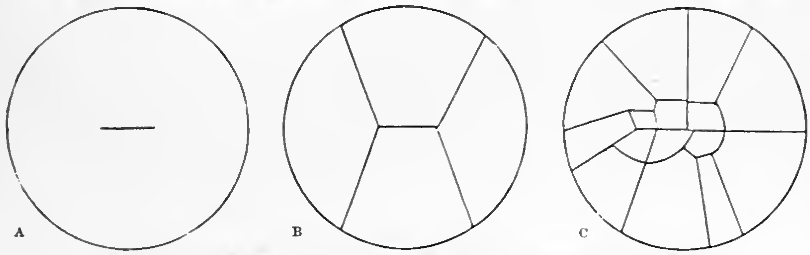


Fig. 4.—Surface Views of the Early Stages of the Segmentation of a Fowl's Egg.

We have thus traced the history of the hen's egg from its earliest appearance in the body of the hen down to the time of its being laid; we have next to see what happens in the course of its development into the perfect chick.

When the egg is laid, the processes which we have been describing cease, unless the egg be submitted to an amount of warmth similar to that in the body of the hen; this may be brought about either in the natural way, by the hen sitting upon the egg, or by some artificial method of incubation. Whichever method be adopted, the subsequent changes are the same.

As soon as incubation commences, the pellucid area gets much more strongly marked off from the opaque area; it, moreover, gets first oval and then pear-shaped, the long axis of the pear lying across the long axis of the egg, at right angles to it. The broad end of the pear-shaped pellucid area will be developed into the head, and the narrow extremity into the tail of the future chick. At the same time, the blastoderm, which, as will be remembered, consisted at starting of only two layers, acquires a third layer, which becomes interposed between the other two. To the three layers of which the blastoderm is now composed special names have been given. The outer layer is termed the *epiblast;** the middle layer is termed the *mesoblast;*† the lower layer is termed the *hypoblast.*‡ As will be seen, these names, however formidable they may appear at first sight, simply signify respectively the layer which is on top, the layer which is in the middle, the layer which is underneath.

From the upper layer will be formed the outer layer of the skin, with the feathers, claws, &c., the brain and spinal cord, and the principal parts of the eyes, ears, and nostrils. From the middle layer will be formed the bones, muscles, tendons, nerves, true-skin, blood, blood-vessels, and the outer coats of the gullet, stomach, and intestines. From the lower layer will be formed the lining membrane of the gullet, stomach and intestines, and of the lungs. We see, therefore, that each layer has a definite and distinct function to perform in the process of development.

As soon as these three layers of the blastoderm are established, a very important process takes place, by which the embryo becomes folded off from the rest of the blastoderm. The manner in which this is effected will be made clear by Fig. 5, which is intended to represent a section taken in a vertical direction from head to tail through the future embryo. The pellucid area, which is at first quite flat, soon becomes marked off from the rest of the blastoderm by a groove, which is represented in section in the diagram, and is roughly in the form of the letter S. This is known as the *head-fold*, and is speedily followed by the appearance of a similar fold at the opposite side of the blastoderm; this latter is known as the *tail-fold*. These two folds grow gradually towards each other,

* Greek, *epi*, upon; and *blastos*, germ.
† Greek, *mesos*, middle. ‡ Greek, *hypo*, under.

the head-fold backwards, the tail-fold forwards, and thus tend to divide the yolk into two portions, as seen in Fig. 6. Lateral folds also grow inwards from each side. The upper sac, which is something like an inverted boat, is the *embryonic sac*, the lower is the *yolk-sac*; these two sacs being connected by a gradually narrowing stalk, the cavity of which speedily becomes obliterated. The embryonic sac grows at the expense of the yolk-sac, the latter supplying nutriment to the former; and a day or two before the chick is hatched the yolk-sac, which by this time has become very small, is slipped into the body of the embryo—that is, the very young chick (Fig. 7).

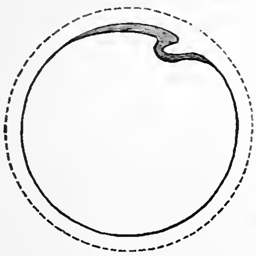


Fig. 5.—The Head-fold.

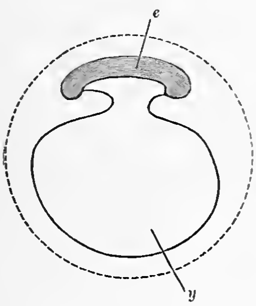


Fig. 6.—Head and Tail Folds.
(*e*) Embryo; (*y*) Yolk-Sac.

While all this is going on, important changes are taking place in the pellucid area itself. First there appears a narrow groove near its hinder (narrower) end—this is the primitive groove (Fig. 8, *pr*). This groove, however, soon disappears, and serves no apparent purpose. In front of it another groove, destined to be permanent, subsequently appears—this is the *medullary groove*, and by the side of it the blastoderm is raised up into two folds, known as the *medullary folds*.

Immediately beneath the bottom of the groove is formed a small, flattened, elliptical rod, which is known as the *notochord*.* This forms the axis round which the future segments of the backbone will be developed. The medullary folds, rising up by the side of the medullary groove, gradually bend over towards each other, and, meeting in the middle line, convert the medullary *groove* into a *canal*. In the front part of this canal, which subsequently becomes closed at both ends, is developed the brain, while in the hinder portion the spinal marrow is formed.

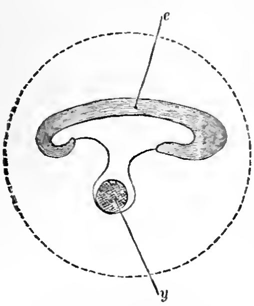


Fig. 7.—Disappearance of Yolk-Sac.
(*e*) Embryo; (*y*) Yolk-Sac.

* Greek, *noton*, the back.

Contemporaneously with these changes the blastoderm commences to grow, and gradually extends itself, immediately beneath the yolk-membrane, over the whole of the yolk. This process, combined with those just described, will tend to produce a structure consisting of two tubes — one formed from the medullary groove in the manner just described the other formed by the closing in of the blastoderm and the gradual disappearance of the yolk-sac. If, however, we consider for a moment the structure of the body of the perfect chick, we shall find that it consists of a single tube in the region of the back, containing the brain and spinal cord, and of a *double tube* below, formed by the body-walls inclosing a second tube formed by the digestive canal. If a cross-section of the body of the chick be taken, the appearance will be that shown in Fig. 9. Evidently, then, some further change must take place in that portion of the blastoderm which is to form the lower tube, as, under present circumstances, it will form only a single tube beneath the one developed from the medullary groove. This further change consists in the splitting of the middle layer into two, the outer portion uniting with the epiblast, the inner portion uniting with the hypoblast. In this way the blastoderm is made to consist of two leaves, which, by gradually developing a space between them, become perfectly distinct from each other. The process by which this is brought about is known as the *cleavage of the mesoblast*. This cleavage commences in the region of the back, at a little distance on either side from the medullary groove, so that on each side of the latter there remains a narrow plate of the blastoderm which is not split. In the same way the blastoderm in the region of the head remains uncleft. A reference to Figs. 10 and 11

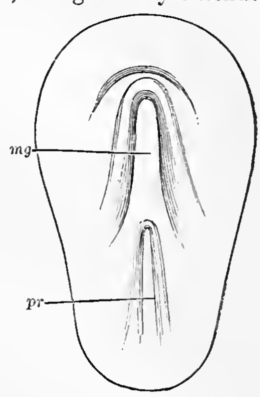


Fig. 8.—Primitive (*pr*) and Medullary (*mg*) Grooves.

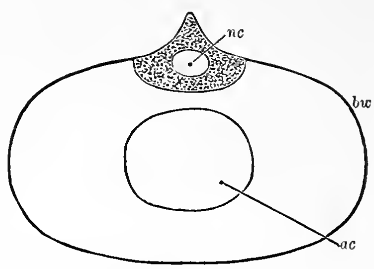


Fig. 9.—Transverse Section of Body of Chick.
(*nc*) Neural Canal; (*ac*) Alimentary Canal; (*bw*) Body-Wall.

will make this clear. Fig. 10 represents the embryo cut across, showing the primitive groove, notochord, and the points where the cleavage of the mesoblast commences.

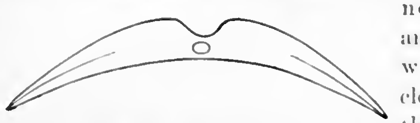


Fig. 10.—Transverse Section of Embryo, showing Cleavage of the Mesoblast.

Fig. 11 represents a section cut lengthwise through the axis of the embryo.

When these two definite sheets of the blastoderm are established, the latter continues to grow over the yolk-sac and to be folded in as before; but the inner sheet is folded in more quickly than the outer, consequently the space between the two sheets gradually increases. The inner sheet will eventually form the walls of the digestive tube, and the outer sheet will form the body-walls; consequently the former is known as the *visceral* sheet, or *splanchnopleure*,* while the latter is termed the *body-layer* or somatopleure.† It will be clear that the space between these two layers will represent the space existing between the body-walls and the viscera in the perfect chick (Fig. 11).

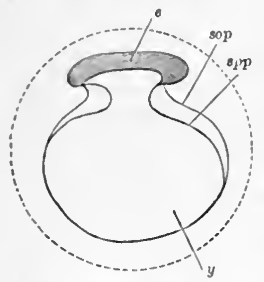


Fig. 11.—Longitudinal Section of Embryo, showing Cleavage of the Mesoblast.
(e) Embryo; (y) Yolk-Sac; (sop) Somatopleure; (spp) Splanchnopleure.

We must now return to the back or *dorsal* region of the embryo. It will be remembered that on either side of the medullary groove the blastoderm remains unsplit for some little distance. Consequently there is on each side of the groove a narrow plate of blastoderm differing from the rest. At an early period these plates, which are termed the *vertebral plates*, become marked out into a number of small square plots by the development of transverse partitions. These little square plots are the so-called *protovertebræ*,‡ or first vertebræ, and out of them will subsequently be formed the segments, or "joints," of the backbone, together with the roots of the spinal nerves and portions of the muscles of the back, &c. These protovertebræ extend backwards from the region of the embryo which is to be the neck of the future chick, but are never developed in the region of the head (Fig. 12).

All the processes which we have as yet described are initiated during the first day of incubation, and, as will be seen, they result in the laying down, as it were, of the general lines upon which the body of the chick is to be constructed. It will, however, be understood that all these changes go on more or less contemporaneously for, in most cases, the whole of the period during which the chick remains within the egg. There is no necessity for us to trace them farther, as it is easily seen that if they are continued until complete they will result in the production of a creature bearing a general resemblance to a fowl; we shall, therefore, devote the remainder of this paper to a brief description of the manner in which certain special organs of the chick are developed.

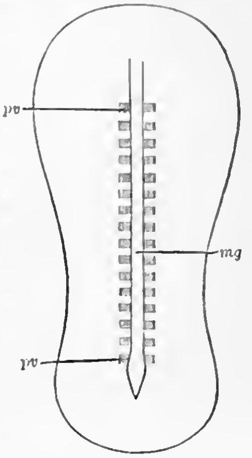


Fig. 12.—The Protovertebræ.
(mg) Medullary Groove; (pv) Protovertebræ.

One of the most obvious requirements for the production of the perfect animal is the development of the limbs, for which, at present, we have seen no provision made. These first become distinctly apparent, about the fourth day of incubation, as small, flattened, conical buds, which project outwards from that portion of the blastoderm where the cleavage of the mesoblast commences. The front limbs or wings are the first to appear, and for some time their development keeps in advance of that of the hind limbs. About the tenth day both limbs are, so far as mere shape is concerned, perfect, but are destitute of feathers and nails, which do not appear till the thirteenth day.

One of the most interesting features of the development of the chick is the formation of the heart and blood-vessels. It must be borne in mind that at the close of the first day the embryo is nothing but a mass of cells which have all been produced from the single cell of the ovum, as found in the ovary of the hen; at this stage, therefore, the embryo chick is precisely comparable with the cellular embryo contained in the seed of a plant. One of the most interesting and important results of the study of embryology has been the tracing of the formation of the various tissues of the body from these purely cellular elements.

About the thirty-sixth hour of incubation there appears just beneath the region of the neck a small mass of cells, which is the rudimentary heart. The

* Greek, *splanchnon*, entrails; and *pleura*, side.
† Greek, *soma*, a body.
‡ Greek, *protos*, first.

cells are formed entirely from those of the middle layer of the blastoderm, and are collected in the space between the body-layer (*Somatopleure*) and the visceral layer (*Splanchnopleure*) of the embryo. At first this mass of cells is solid, but it speedily acquires the form of a hollow tube, containing a small quantity of imperfectly formed blood. Considerable doubt for a long time existed as to the manner in which the rudimentary heart became hollow, but it seems now to be certain that its cavity is formed by the central cells of the mass becoming liquefied and forming blood, while the outer cells become gradually developed into its muscular walls. Almost as soon as the heart is thus laid down it begins to pulsate, slowly at first, but with the increasing development of the walls the pulsations soon become more regular and more rapid.

To thoroughly understand the further steps in the development of the heart, we must remind our hearers of its structure in the perfect fowl. The heart consists of a hollow muscular (fleshy) organ somewhat in the shape of a blunt cone. Internally the heart is divided into two halves by a muscular partition, and these two halves are known respectively as the right and left sides of the heart, and they do not in any way directly communicate with each other. Each half of the heart is again divided into an upper and a lower chamber, which communicate with each other by an opening guarded with a valve so constructed as to allow of the blood passing from the upper chamber to the lower, but not in the opposite direction. The heart of the fowl will thus be seen to consist of four chambers, two upper and two lower; the former are the receiving chambers, and are termed *auricles,* the latter are discharging chambers, and are termed *ventricles.* Into the auricles the blood is poured by the great veins, from the auricles it passes into the ventricles, and from the ventricles into the arteries. The right side of the heart receives blood which has been all over the body and has become impoverished and impure; by the right ventricle this blood is driven into the *pulmonary artery,* which conveys it to the lungs (*pulmona,* a lung). In the lungs the blood becomes purified, and is returned from thence by the four *pulmonary veins* to the left side of the heart. Finally, from the left ventricle it is driven into the large artery, the *aorta,* by the various branches of which it is conveyed over the system generally.

Having seen the structure of the heart and its connection with the principal blood-vessels in the fowl, let us return to the heart of the embryo, which, it will be remembered, we left as a simple tube. The first step in its further development is the marking off of the tube into three parts by constrictions, as shown in Fig. 13. The lower part will become the future auricles, the middle part will form the ventricles, while the upper part will form the roots of the great arteries (pulmonary artery and aorta). As development proceeds, the tube gets bent, so that eventually the ventricular portion comes to occupy the lower position and to be pointed towards the left side of the embryo. At the same time the auricular portion is made to occupy the upper part of the heart, carrying with it the great veins, while the arterial portion occupies the front upper aspect. These changes are shown in Fig. 14.

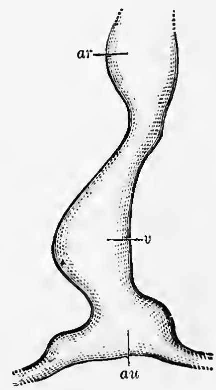


Fig. 13.—Development of the Heart of the Embryo. (*ar*) Arterial Bulb; (*v*) Ventricle; (*au*) Auricle.

Meanwhile partitions are developed in all three portions of the heart, whereby the ventricular and auricular portions are formed, each into two distinct chambers, and the arterial portion into two distinct vessels—the aorta and pulmonary artery. It is worthy of notice that the partition between the auricles remains for some time incomplete, so that before the chick is hatched there is a direct communication between the right and left auricles. At the time of hatching this opening is closed up.

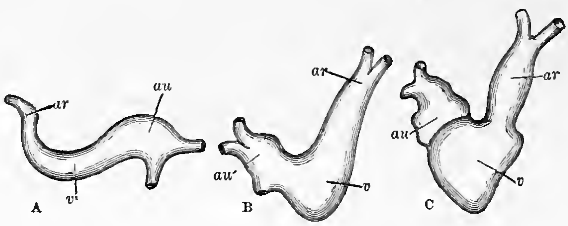


Fig. 14.—Final Changes (A B C) in the Heart of the Embryo. (*ar*) Arterial Bulb; (*v*) Ventricle; (*au*) Auricle.

The formation of the blood-vessels is brought about, according to the observations of Messrs. Foster and Balfour, in the following manner:—In the middle layer of the blastoderm a number of cells at different points are seen to send out long "processes" (protuberances) which, uniting together, form a rudimentary network, the cells answering to the knots of the network. These cells speedily multiply by dividing, and eventually the innermost cells become liquefied, and the outer

cells are aggregated together and modified, so as to form the walls of the blood-vessels at these points. In the same way the "processes" between the cells become modified so as to give rise to blood inside and to the walls of the blood-vessels on the exterior. In this way that wonderful system of blood-vessels which permeates every part of the system is gradually developed.

We have dwelt somewhat at length upon the development of the blood-system, because it affords one of the most perfect and most easily comprehended instances of the formation of a series of highly complex structures from simple cellular elements. The development of the other organs of the chick we can only briefly refer to. We have already seen that the gullet, stomach, and intestines (forming the so-called alimentary canal) are formed by the folding in of the visceral leaf (Splanchnopleure) of the blastoderm. As outgrowths of this canal, are formed the liver and other glands connected with digestion. The lungs are also formed as outgrowths of the gullet, from which they subsequently become detached. The brain and spinal cord are formed in the medullary canal, as already stated, from the epiblast, the nerves being derived mainly from the mesoblast.

The ear and eye are formed partly by the folding inwards of the integument and partly by outgrowths from the brain, while between these two elements cells from the mesoblast are interposed.

We have here briefly summarised the principal facts connected with and explanatory of the history of the hen's egg from its earliest formation to its complete conversion into a perfect fowl, and our readers will, we are sure, agree that it is a history as interesting as it is wonderful. But, however interesting it may be when considered merely as an isolated instance of development, it gains tenfold in interest when we consider it in connection with the rest of the animal world; for it is one of the greatest triumphs of modern science that it has shown the development of the chick to be the type of the development of all the higher animals, including man himself. With some slight modification of details, all that has been said with regard to the developmental history of the chick would be equally true if applied to the development of the human subject.

GROWTH.

By Andrew Wilson, Ph.D., F.R.S.E.

THE observant and thoughtful reader, who has stood on a sea-beach and watched the rippling waves breaking upon the shore and arranging the shining sands in long-drawn-out lines of golden hue, may perchance have allowed his thoughts to wander from the fair scene before him, and to dwell upon some of those phases of this world's history in which sand and sea play no unimportant part. The history of sand-particles carried off by the waves to farther depths of sea, there to be worn down to still more minute bulk, and finally to be added to the deposits of the sea-bed, constitutes in reality a chapter in the growth of the world itself. From such deposits, torn from the land and arranged by the sea-waves, the rocks of the past have been made, as the rocks of the future are being formed to-day. And could our imagination, aided by scientific bent, picture the future disposal of the existing matter of our earth, we should be surprised to find how large a share of this world's growth depends upon the continuous work of such minor agencies as the brooks and rills of our land, or the "toying wavelets of a summer's sea." From such a thought and from such a special phase of geological study, which sees in the waste of one world the elements which provide for the growth of the next, our mind naturally turns to the nature of growth and increase in the universe at large. Unconsciously to ourselves, we picture growth as a universal condition of the world in which we live. The dead or inorganic matter of the world is everywhere being added to, and no less does the world of life exhibit a constant increase as its unvarying heritage. Life and growth mean one and the same thing; they are, in truth, convertible terms. The most familiar phases of animals and plants appear before our eyes as the results of orderly increase; and even the expectation of "seed-time and harvest," the hope of a "golden reaping" after the green blades of spring, is but a simple assertion of the fact that growth and increase are essential facts of life.

An instructive study may be said to lie before us if we endeavour to discover the modes and

fashions of growth which prevail in the world at large. In the contrast between the increase of the lifeless world and that of the universe of life, we may light upon many facts of importance far beyond that which attaches to a passing interest in the subject of growth itself. And our survey may also tend to show us how beautifully correlated are the forces and actions of nature as exhibited both in the non-living world, and in the sphere of life which that lifeless universe may be said wholly or in greater part to sustain.

The growth of non-living things differs very materially from the increase of animals and plants. Rocks, and dead or inorganic bodies at large, may be said to grow in one chief fashion. They increase by the addition of new particles to their outside surfaces. The fresh matters are deposited simply on the outside of the old, and without any special reference to the previously existing materials. A rock grows, in short, very much as a snow-ball increases in size. The new particles of snow are added, in the case of the snow-ball, to the outer surface, and bear no relation to the matter of which the snow-ball already consists. Now, this process of outside growth is known as that of *accretion;* and, as we have just said, such a mode of increase is characteristic of the inorganic or lifeless world at large. Rocks grow by the addition of fresh particles which are deposited on the outside of the already-formed materials; and a similar process may indeed be said to have marked the growth of the universe itself, viewed as an individual planet amongst the countless orbs that circle through space.

But more exact and detailed observation of the process of growth and increase in the world of non-living matter, shows us some interesting and curious features included in the work of "accretion." There are some phases of growth in lifeless bodies so marvellous, that at first sight they might seem to mimic the more intricate increase of living beings. Such are the phenomena observed during the crystallisation of fluids, when atom is added to atom, and particle to particle, with a regularity infinitely more exact than that which guides a bricklayer in the adjustment of the elements of his wall. A saturated solution of alum, or nitre, or sugar, will exhibit the wonderful phenomena of crystallisation in their full glory. Under scientific treatment, we see how the atoms of each substance rush together to combine in crystals of special and unvarying form in each case, and we note in this action the influence of that reign of law which rules atoms and worlds alike. To see a solution of sugar of lead decomposed by the electric current, is a sight at once curious and instructive. The lead-atoms, liberated by the electric influence, build themselves into crystals of wondrous beauty of form, and mimic the graceful symmetry of plant-life with marvellous exactitude. So astonishing is this process of the building of this leaden vegetation, that one is at first sight tempted to think of the growth of a living being, and most naturally of the sudden growth and increase of some fairy plant. But in Nature's own laboratory the process of crystallisation, and the wonderful results of its action, are as readily to be observed as in the chemist's workshop. "Jack Frost's" decorative exertions

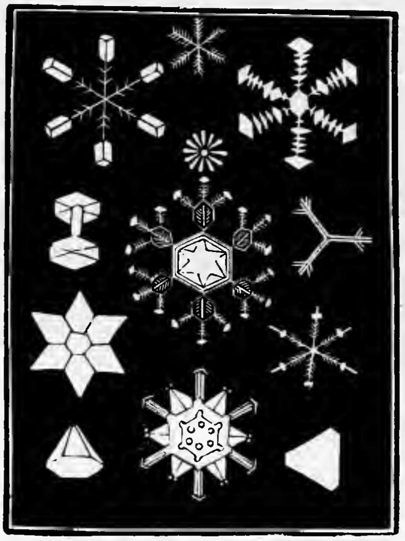


Fig. 1.—Snow Crystals.

on our window-panes present us with an apt illustration of the orderly arrangement of the atoms of water to form the frost-crystals and the fairy tracery of a winter night. And if we take the trouble to look at the crystals of snow (Figs. 1 and 2), and mark their elegant symmetry—arranged like rock-crystals in sixes—we may find exquisite beauty of form and mathematical regularity of outline exemplified in the world's white drapery itself. Even the ice-blocks can be shown to be built up by interlaced crystals. For when a beam of the electric light is sent through a block of ice, that substance melts and undergoes liquefaction in its interior, beautiful six-sided spaces or ice-flowers appearing around the little shining points which soon exist everywhere within the ice-block.

Wondrous and impressive as are these processes of crystallisation, we must be careful to note the

exact fashion in which the crystals grow. Like the snow-ball, they are the products of "accretion;" they grow by the addition of new atoms to their

Fig. 2.—Snow Crystals.

outside surfaces. A crystal of alum, of sugar, or of salt, immersed each in a solution of its own substance, will grow, in virtue of the laws and actions by which it attracts the particles towards itself. And although there is much that is curious and everything that is wonderful in the process, it is after all a purely mechanical action. There are no limits to its extent; the crystal will be neither better nor worse for the additions made to it, save in point of size. There is no active response made by the crystal itself to the atoms which it attracts, just as these particles in their form evince no intimate relationship with, or interest in, one crystal or another. And of the formation of larger bodies than crystals the same remark holds good. How, for example, have those curious lime-pillars found in limestone-caves, and named *stalactites* and *stalagmites*, been formed? These icicle-like pillars of lime sometimes attain a very large size, and may weigh many tons. Standing in one of the larger limestone caves of the world, one might with little stretching of imagination fancy that he stood in the aisle of some primitive cathedral, flanked by massive rock pillars and columns of giant size. That these cave-pillars must have "grown" is a self-evident fact. Their very appearance is indicative of gradual growth, and their history may, therefore, present us with a very typical example of how lifeless things grow. Their source of origin relates them to water charged with chalk (*carbonate of lime*), which has been formed by the union of the gas called *carbonic acid* (contained in the water) with the lime (obtained from the rocks). Underground, water and its dissolving powers are responsible for the work of excavating limestone caves themselves, and from the roofs of such caves water is continually dropping. This water, laden with its chalk-atoms, trickles in drops from the cavern-roof to its floor. Resting for a moment on the roof, each drop of water leaves attached thereto a few particles of its limy burden, the water being diminished by evaporation, and being therefore unable to carry as much lime as before. Now, let us multiply our water-drops by myriads, and the period during which they drop by centuries, and we shall find that in due time the stalactite will come to depend from the cavern-roof, formed thus by an action so trifling when casually viewed as hardly to merit attention, but seen to be powerful almost beyond realisation when its elements are multiplied by numbers, and its duration by cycles of years. Nor is this all. A similar process of evaporation of part of the water-drops takes place on the floor of the cave, and slowly, but surely, built up thus particle by particle, the stalagmite grows upwards towards the roof, as conversely the stalactite grows downwards towards the floor. Whilst occasionally, the stalactite will unite with the stalagmite to form a complete and perfect limy pillar, obstructing the cave from roof to floor. Thus we see that the regular growth of these lime-pillars, which as natural objects grow regularly and, as a rule, symmetrically, is like the formation of crystals, a matter of outside increase or "accretion." And the further lessons we may derive from the study of such productions, may be recapitulated and summed up in the remarks — first, that the process is a purely mechanical one; secondly, that the object which grows or is being formed evinces no sympathy or interest in its increase; and thirdly, that the continuance of the process of increase, or its stoppage, would be attended with no disastrous results to the lifeless thing—crystal or stalactite, as the case may be—save, indeed, as producing a mere difference in size or form.

The consideration, even casually, of the common history and every-day life of animals and plants

reveals, on the other hand, a widely different state of affairs. Indeed, the process of increase in a living being is opposed, in a very striking fashion, to that we have just noted as occurring in the world of non-living matter. Let us endeavour briefly to trace the processes by means of which animal and plant respectively attain their full development, and we may learn how characteristic and varied are the laws and powers which rule the increase of the world of life. Selecting the seed of a pea or bean as typical of the ordinary course of plant-growth, we speedily discover that it is the seat of powers of very different character from those which hold sway amongst the crystals and ice-atoms. Split the pea or bean lengthwise (Fig. 3 B), and you find it to be

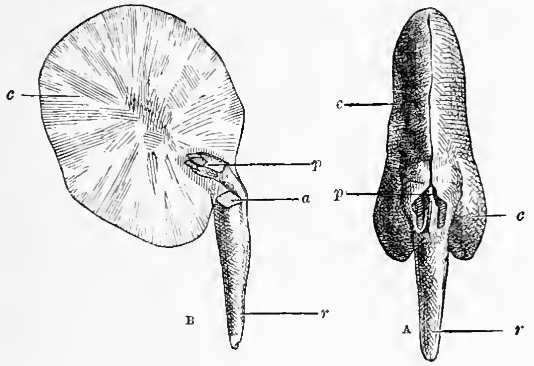


Fig. 3.—Bean: (A) Embryo with Seed-coat removed; (B) Embryo minus one Cotyledon.
(*a*) Point of Separation of Cotyledon.

made up of two bodies, named *cotyledons*, or *seed-leaves* (*c*), which are, however, unlike "leaves" in the present instance, and which appear simply as two fleshy lobes, containing material for the nutrition of the young plant. The *embryo*, or young plant itself, exists as a little projection towards the concave side of the bean, and we may distinguish even now the first beginning of a *root* in the little

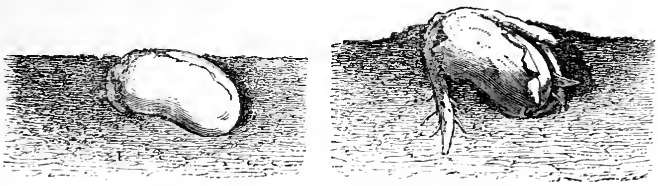


Fig. 4.—Haricot Bean Germinating. (*First Effort.*)

radicle (*r*), and the first traces of a *stem* in the little *plumule* (*p*). Kept above ground (Fig. 4), the seed exhibits no traces of vitality. It has no tendency to attract matter towards itself, save under certain conditions—these latter being its insertion in the ground, and the presence of heat and moisture. Soon after its insertion in the ground, we note the development of active powers, which result in the bursting forth of the little stem, and in the downward growth of the root. Time passes, and leaves appear (Figs. 5 and 6); growth is active in every part of the new plant, and its full fruition is marked at last by the crowning glories and successive stages of flower, fruit, and seed; so that we return with the seed to the point at which our observation of the plant began.

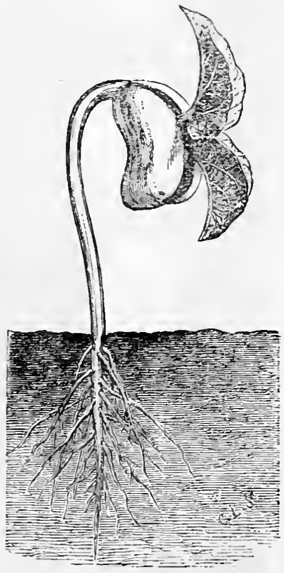


Fig. 5.—Haricot Bean Germinating. (*Embryo bursting through.*)

The course of ordinary plant-history, however, has no special attraction for us at present. Our inquiry directs us rather to the query, How have the results of that history been attained? How does the plant provide for its growth? How are bud and blossom, leaf and flower, fruit and seed, produced and evolved, as the results of growth and increase? The replies to these questions will serve instinctively to show us the wide gaps which separate the living from the lifeless world. It requires no exercise of thought to perceive that the mode of growth of the pea or bean is certainly not that of the crystal or the stalactite, which themselves are but types of all lifeless things. The crystal increased by additions to its outside surfaces, and the frost-ferns on the window increased likewise by external growth, and by mere accretion. There was no growth or expansion of one crystal into many, nor of one ice-particle into a frost-fern. In the plant, on the other hand, we saw that the "seed" containing the "embryo," or young plant, by a process of *development*, produced the new being. The crystal grew by mere addition; but in the plant there was seen the production and evolution of new and varied organs from parts and structures which were at first of similar nature. Internal *development*, and not outside addition, is clearly the law of living growth. The crystal can only extend its own form by the most mechanical of processes. The living being produces, by complicated processes, organs

and parts of which the seed, or germ, gave no apparent promise. It is thus observed that the living plant and its germ are the seats of powers and acts which are utterly unrepresented in the world of non-living matter.

Nor does the growth of a plant differ from that of a crystal only in these details. The outside growth of the crystal, or stalactite, is not merely opposed by the inside growth of the living being, as we have seen, but the matter upon which the living being subsists is unlike itself. The crystal of alum

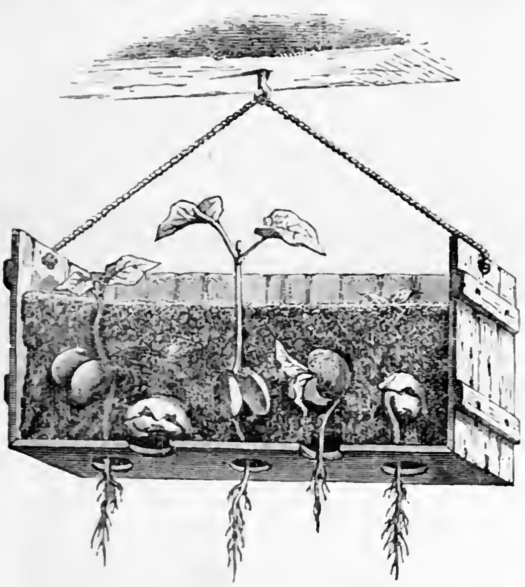


Fig. 6.—Germination of the Haricot Pean.

or sugar will only grow if placed in an alum and sugar-solution respectively. The saying that "like draws to like" is really and literally true of the growth of non-living nature. But the young plant in its earliest phases of development, and from the moment when its primitive rootlets extend downwards into the soil, takes to itself from the outer world matter that is unlike itself. If we obtain an analysis of our plant, the chemist will inform us that it is a highly complex body. It contains starches and sugars and fats, and many other matters, which as such are not to be found in the soil into which its roots penetrated, or in the air into which its stem grew. From the soil it obtained water and mineral matters, the air supplied it with carbonic-acid gas, and the soil and air together gave it ammonia. Upon these substances, and under the genial influence of the sun's light and heat, the plant grew, and transformed its "food"—as we term the matter drawn from the outer world—into the complex sugars, fats, &c., of which its body was composed. Here there has therefore been performed an action of which not the slightest traces are discernible in the increase of the crystal. The plant has taken matter unlike itself from the outer world, and it has further, by the exercise of its vital chemistry, transformed this matter into the substances of which its body is composed.

Nor should we find the story of the animal and its growth to be less remarkable than the history of the plant. The animal grows from its egg, as did the plant from its germ, by the absorption from the outer world of "food," that is, of matter unlike itself. By the exercise of the powers with which life has invested it, the animal is capable not only of appropriating such matter, but of converting it, like the plant, into the substances of which we know the animal frame to consist. And thus both animal and plant grow by a process the exact opposite of "accretion," and which we name *intussusception*—the receiving of matter *within* the body. Nor must we neglect to add to this primary difference between living and non-living increase, another which calls upon us to remark that the matter added to crystal, or stalactite, is unaltered in character, and is usually of a similar nature to that of which the non-living body is composed. Sugar particles are added to sugar particles in the work of crystallising that substance, like being added to like; and even if substances of a foreign nature be added to a living body, the occurrence is purely accidental, and tells neither for nor against its growth. Within the animal or plant body, on the contrary, there is a process of conversion of the matter drawn from the outer world into its own tissues. The living being transforms the matter upon which it exists. Hence we recognise in the word *assimilation*—the "making like"—the true expression of the work of the living being in building up its frame from varied matter. Very wonderful is it to reflect upon the material sources whence the beauty, splendour, grace, and harmony of living nature have been derived. The fragrant flower and gorgeous blossom—leaf and petal alike—simply represent the transformed materials upon which the plant fed; and the plant itself is merely so much matter derived from the outer world, and elevated, by the magic power of vital action, from the inorganic universe to the world of life.

Such are some of the most apparent distinctions between growth and increase in a living body and in a lifeless object. Yet another consideration of importance remains in the teachings of physiology

regarding the growth of a living being in its intimate, or minute, parts. The crystal is unquestionably formed according to laws which preserve a definite symmetry and shape. The stalactite, or rock, on the other hand, may grow in diverse fashions as to form or configuration, and the new matter may be added to such inorganic objects either symmetrically or the reverse. If the water-drops fall upon one side of a stalactite, or are otherwise made to add to its bulk in an unequal manner, the result will be an unsymmetrical figure; but this result cannot be said to affect the nature of the stalactite, which is just as typical even if it be lop-sided as when it is symmetrical. Opposed to such thoughts regarding the mechanical additions to the outside surfaces of inorganic, or lifeless, objects, we find in animals and plants certain very marked and different phases of growth. The living being grows in all in its parts, and grows symmetrically, under normal conditions. This intimate and well-regulated increase of every organ and tissue of the most minute parts, forms one of the most striking features of life at large. The body of an animal or plant literally grows through the growth of its most minute elements. Physiology reveals a wondrous tale when we inquire into the manner in which growth and nutrition are performed in living beings. Each tissue is seen to be composed of minute *cells*, or of *fibres* which were formed originally from "cells." To these microscopic elements the nutritive fluid—blood or sap—is duly conveyed. Each tissue has the power of taking from this common fluid the elements necessary for its growth and increase; and the cells and tissues of living bodies thus appear like varied buyers of raw material in a common market, whence this raw material is conveyed, and elaborated thereafter into equally varied forms of manufactured products. Thus it is that from the sap the young leaf-cells manufacture new cells, and in due time develop the leaf. Thus from the same sap the early tissues of the flower will form an entirely different structure, and produce the blossoms with all their richness of hue and varied structures, organs, and parts. Thus, too, stem and root, and every other part of the plant, increase and grow through the manufacture, by the minute elements of the tissues, of other elements like themselves. And so in the world of animal existence. There exists in the animal body a similar process of growth by littles. From one and the same blood, nerve-cells and nerve-fibres make new nerve-tissue; from the blood, bone reproduces bone; and each and every tissue adds to its extent in like fashion. Growth in a living being is, therefore, not merely internal, but is also a process affecting the most minute elements of the living frame. And no part of the puzzle of life can be said to present greater difficulties in the way of exact comprehension than that which concerns itself with the "how" and "why" of those actions and laws, in virtue of which the increase of our frames, throughout the most minute portions of their extent, is so marvellously regulated and so harmoniously controlled.

The subject of "growth" would be incomplete were we to close this paper without reference to certain unusual fashions in which, as observed in the animal world, growth may be performed. In both groups of living beings the minute "cells" already alluded to determine by their manner of increase that of the animal or plant as a whole. But studied generally, and especially in lower animal life, certain forms of growth and increase, altogether exceptional in the ideas of popular zoology, are to be noted. Thus we may note that the production of new beings in certain animalcules (such as the *Infusorians* found in stagnant water and elsewhere) may be effected through a simple process of actual division of one body to form two. It is a perfectly common occurrence for an infusorian to divide either crosswise or lengthwise

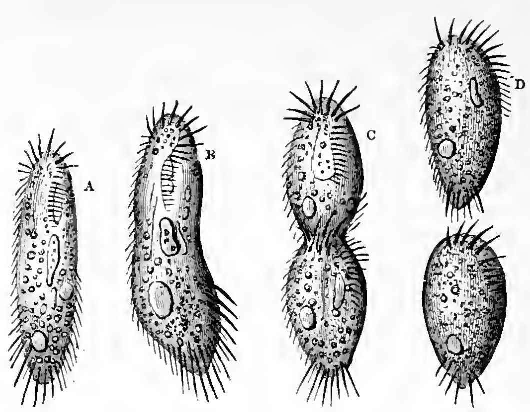


Fig. 7.—Propagation of Infusorian by Spontaneous Division.
(A, B) the Adult; (C) the Same in Course of Separation; (D) the Same after Division.

(Fig. 7) into two individuals, which, by a subsequent process of ordinary growth, attain the size and rank of adult beings. Artificial modes of growth and reproduction, so to speak, may be experimentally practised on some animals, such as the *hydræ* and sea-anemones. The *Hydræ*, or "fresh-water polypes,"—whose history will be treated at length in a future paper—are little animals, found attached to water-weeds, possessing a simple tubular body, terminating

in a mouth and tentacles at the free extremity. The average length of a hydra is about a quarter of an inch. As Trembley, of Geneva, showed about the middle of last century, a hydra may be cut crosswise or lengthwise, when each half or portion will grow to be a perfect little polype. Trembley's

Fig. 8.—Sea-Anemones.

own words, referring to one experiment of this kind, are: "I put the two parts [of the cut hydra] into a flat glass which contained water four or five lines in depth, and in such a manner that each portion of the polype could be easily observed through a strong magnifying-glass. It will suffice to say that I had cut the polype transversely, and a little nearer to the anterior. On the morning of the day after having cut the polype, it seemed to me that on the edges of the second part, which had neither head nor arms, three small points were issuing from these edges. . . . Next day, they were sufficiently developed to leave no doubt on my mind that they were true arms. The following day two new arms made their appearance, and some days after, a third appeared, and I could now trace no difference between the first and second half of the polype which I had cut." Here there would seem to be literally no limit to the artificial growth and production of new animals. Similarly, in sea-anemones (Fig. 8), as the writer has experimentally satisfied himself, the process of artificial section and division may be carried out much as in hydræ, and with equally fertile results. But this process of *fission*, *cleavage*, or division of the body may proceed naturally in some animals, such as corals, where it results in the production from one coral polype of two or even more new individuals.

Not less remarkable in the animal world is the occurrence of a veritable process of growth by *budding*, of as true and typical kind as is witnessed in the plant world. In the corals we see this process exemplified in the production of new buds from the already formed parts and animals. And the process of budding is even better illustrated by the zoöphytes, to whose exact personal history we may return on another occasion.

A zoöphyte possesses a root, stem, and branches, and even leaves are represented by the little bodies one can perceive to be borne on the branching parts. Such an organism perfectly mimics a marine plant—as such, indeed, it is gathered by the non-zoological observer who collects the common objects of the shore in his holiday stroll. Watch such an organism as this zoöphyte in life, and you will behold a wondrous spectacle. The branches are studded with little animals, each possessing a mouth and tentacles, and each connected with its neighbours, and forming a unit in this remarkable colony of lower life. Through the hollow stem and branches the vital fluids continually flow; and, as each little member of the colony aids in elaborating the supply of fluid from which it draws its own meed of support, an unselfish principle of co-operation is seen to be most admirably represented in the miniature society before us. Interesting as is the history of the zoöphyte, we may concern ourselves at present with but one feature in its biography, and inquire how its growth is carried out. Like the leaves of the tree, the animal buds of the zoöphyte undergo continual degeneration. They wither and fall by a process of natural decay as do the leaves of plants; but, curious to tell, new members of the colony are duly budded forth to supply the place of the lost members, and the animal form thus repairs the ravages of death in similar fashion to its plant neighbour. Nor is this all. The zoöphyte became the curious colonial and compound organism you behold through the same process of budding which enables it to hold its own in the struggle for existence. Liberated from an egg produced by a previously-existing zoöphyte, the little free-swimming animal settled down, rooted and attached itself, and developed a single little organism. Soon this first being, by a process of budding, gave origin to another like itself, the two remaining connected together in closest union; other buds were in due course rapidly produced by these primary forms; and, through this process of continuous budding, the compound plant-like colony was established. So strikingly similar is the animal to the plant in such a case.

We thus observe that the growth of the animal may in some cases be carried out in fashions allied to those in which plant-life repairs the loss of its parts, and renews its form. One concluding thought concerning growth may be fitly mentioned in connection with the relations of growth to the general decay and termination of living existence. The natural and unending continuance of the world of non-living matter, is a fixed observation which follows the contemplation of the comparatively unchanged and unaltering existence of inorganic objects. The rock or boulder crystal, or stalactite, viewed as to its existence, is dependent solely on outward conditions for the duration of that existence, and receives the measure of its span from the forces of the world without. Very different is the tenure upon which the existence of living beings is founded and held. The duration of life is based upon the internal constitution and inherited nature of the living being, and the span of its existence is measured, in ordinary circumstances, by laws written for its guidance in the history of its race. Hence, physiology teaches us to view the death of an animal or plant as the most natural result of its existence, and as a phase of life as primary as the fact of existence itself. The duration of life is as surely written for each species or race as are the laws of its growth; and in truth growth and decay may be said to bear the closest possible relation to each other. The tooth, which, after a normal period of growth, has its roots undergoing absorption and degeneration, and which finally falls from its socket, obeys the laws of its life, and has its growth beautifully correlated with the normal period of its existence, and with the time of its decay.

And what is true of one organ or tissue is true of the entire animal and plant frame. Such a thought of the correlation of life and growth with extinction and decay, forms a consoling idea when viewed with regard to the measure of human life itself. Since we perceive that the end of existence, dreaded and feared as a part of the unknown and unknowable in nature, is as wisely ordered and as perfectly adapted to the facts of life as are any of the other phases of which our existence is composed.

THE MAGIC LANTERN.

By John Thomson, F.R.G.S., Author of "Through Cyprus with the Camera," etc.

Most of our readers are familiar with the Magic Lantern of boyhood's days, an instrument as simple as it was cheap, and whose grotesquely-painted slides enlivened many a winter's night. This optical toy, like a host of others with which we are acquainted, has developed into a form so complex, and thoroughly scientific in the uses to which it is applied, as to be hardly recognisable.

Before proceeding, however, to give an account of the various improvements effected in the construction of the lantern, and of the mode in which it has been fitted for its noble functions, let us glance at the instrument in its primitive form. It is thus disposed of in a Dictionary of Science compiled some forty years ago. "An optical instrument by means of which small figures, painted with transparent varnish on slides of glass, are represented on a wall or screen considerably magnified. It is generally used as a toy, and affords amusement from the grotesque character of the figures." The author goes on to say that it is also employed to enlarge diagrams used in Astronomical lectures so as to be seen by an audience. This then was the first scientific use to which the lantern was applied; but the commencement of a new era in its history is coeval with the discovery of photography.

At the time when Daguerre and Talbot were independently solving the problem of how to fix the photographic image, the instruments at their disposal were rudely constructed, and ill adapted for the requirements of the new art. As soon as photography had become an accomplished fact, a host of eminent men entered the field of research. The fruits of their labours appeared in a store of improved cameras, lenses, and lanterns.

As the history of the photographic camera and magic lantern run in parallel lines, we cannot divorce the two instruments. The object-glasses are, or ought to be, similar in both, in so far, at least, as their properties are concerned.

The toy lantern in its general arrangement has undergone no change. Its various parts have only been modified and perfected in the best instruments. In its earliest form it had a dark tin casing, and a chimney, an inner light, a condensing-lens, a reflector, a stage, and an object-glass (Fig. 1).

There is an oil-lamp, or argand burner within the closed lantern B; M is a concave mirror to throw the light on a condensing-lens C; thence the light is passed through the condenser and concentrated upon the object to be magnified. S is the stage which supports the slide, and P the tube containing the object-glass by which the image is thrown upon the screen. In order to arrive at a clear understanding of the subject, it is necessary to explain what is meant by a lens. A lens is simply a magnifying or a diminishing glass—magnifying when one or both sides are convex, and diminishing when one or both sides are concave. The first causes rays of light, from a distant source, such as the sun, to converge to a point or "focus" when they pass through it, and the second causes rays to diverge. On the same principle convex lenses produce images of objects placed before them in their "foci," enlarged or diminished according to the relative distances from each other of the lens, the object, and the screen upon which the image is thrown. The magic lantern is so arranged as to enlarge transparencies placed in its stage. But the simple convex, or plano-convex lenses first used in the lantern and in photography were ill suited for their task. They had defects known as spherical and chromatic aberration, which so marred the images when magnified as to render them useless for the purposes of science.

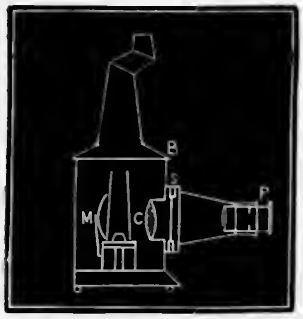


Fig. 1.—Simple Form of Magic Lantern.

When photographic transparencies were substituted for rudely painted slides, object-glasses "achromatised" were applied to the lantern. These were so constructed as to magnify objects to an indefinite degree, and at the same time to disclose charming details in the photographic transparency such as could not be detected by the naked eye.

One of the finest early examples of this beautiful application of photography was shown in Professor Piazzi Smyth's photographs of the Pyramids. The original pictures were taken on a uniform scale of one inch square. Out of one of these a section of one-eighth of an inch was selected and enlarged in the camera, so as to form a slide for a lantern. The picture was nothing more than a patch of desert sand; but when magnified by the lantern the grains of sand became fragments of rock mingled with shells of marvellous mould, and of diverse forms. Here then was a revelation of the educational power of this modest toy, the lantern, which has since borne fruit in ways almost incredible.

We will now proceed to discuss at greater length some of the most noteworthy improvements in the construction of the lantern.

First we will consider the light, as it is the chief factor in all questions relating to the magic lantern. The days of the oil-lamp appeared to be numbered after the introduction of coal gas, but this primitive illuminator has been so modified as to find favour in our own time. Half a century ago the argand lamp, with its glass chimney, was used in the best lanterns, and when skilfully managed yielded results as satisfactory as could be obtained by coal gas.

Quite recently a modification of the oil-lamp has been introduced in what is known as the sciopticon, or photogenic lantern. The light is produced by a new burner requiring no glass chimney. In its most recent form the burner A (Fig. 2) is supplied with a triple arrangement of wicks, each wick having a rack and pinion adjustment connected with the milled heads at B.

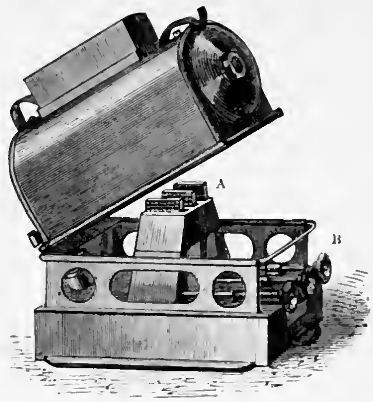


Fig. 2.—Wick Arrangement in Sciopticon Lamp.

Rock-crystal oil is used, and the flame produced far exceeds in uniformity and brilliancy the light obtained by the argand burner. But the advantages conferred by this form of instrument do not end with the lamp; and we may as well mention its properties before entering upon the subject of the oxy-hydrogen light.

This little instrument, which figures in catalogues under a number of different names, consists entirely of thin wrought iron, and is so admirably planned for ventilation that it is not liable to get over-heated. It is designed also for extreme

portability. The chimney may be removed and the whole packed into a small case. This is the best form of lantern now in use for small rooms, where a brilliant picture is required not exceeding six feet in diameter.

The greatest advance in the illuminating power of the lantern was obtained by the adoption of the oxy-hydrogen or lime-light.

In 1826, Lieutenant Drummond partially succeeded in establishing this as a light of the first order. But the old system had many defects which have been done away with. Among these was the tendency of the lime cylinder to crack and moulder away under the intense heat produced by the combustion of the two gases, oxygen and hydrogen. This rendered the light fitful and uncertain. Then, again, the gasometers were huge and unwieldy, and could not be easily carried about. The paraphernalia, indeed, used by one of the first lime-light lantern exhibitors had to be transported from town to town in a specially-constructed van, so that the lecturer, with his belongings, looked as much a wandering showman as a man of science.

One of the earliest forms of the oxy-hydrogen jet applied to the lantern was made with a Bunsen burner, which served the double purpose of heating the lime to prevent cracking, and supplying hydrogen—let us say rather coal gas, or carburetted hydrogen, which answered the purpose and ultimately replaced the purer gas. The jet is

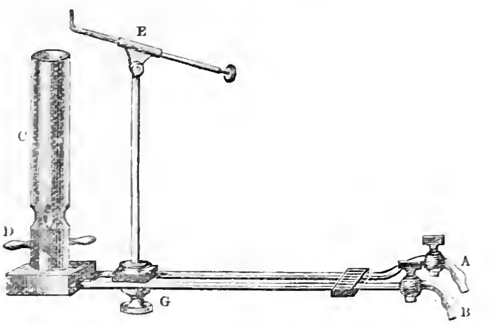


Fig. 3.—Early Form of Oxy-Hydrogen Jet.

represented in Fig. 3. A and B are two separate tubes, the one supplying oxygen and the other hydrogen gas.

The oxygen tube is carried to the top of the Bunsen burner C, while the hydrogen passes into the Bunsen tube. This tube is provided at D with a sliding shutter, by which the current of air may be excluded when the jet is in action. An upright rod, sliding between the gas-tubes, and which may be fixed at any point by the screw G, supports the lime-holder E. This lime-holder is simply an iron rod, to which is imparted a universal motion, in order that the lime-disc may be so adjusted as to receive the mingled gases at the point of combustion.

This form of jet has been superseded by a variety of others, from which the Bunsen burner has disappeared. Of these Fig. 4 is one of the most modern. It has two interchangeable jets (A and B).

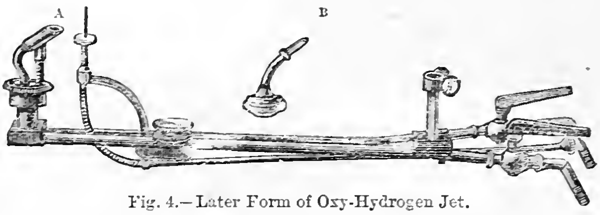


Fig. 4.—Later Form of Oxy-Hydrogen Jet.

In the one the gases mingle at the nozzle just before ignition, while in the other they are mixed in the chamber beneath the jet. The greatest illuminating power is obtained by the use of the jet B, but it can only be employed with safety when both gases are under equal pressure.

In the lime-light lantern there is no reflector; the luminous rays are taken up by the condensing-lens and concentrated upon the slide.

We now come to consider the optical principle upon which the magic lantern is constructed. After the light, which is of primary importance, follows the combination of lenses by which the light is utilised. These are the condenser and the object-glass, or "objective."

The condenser is made up of a combination of two, three, or even four lenses, set in a tube facing the light, and so devised as to be free from spherical and chromatic aberration. At the same time the arrangement, in its best form, takes up a wide angle of light. This arrangement, as its name implies, is used to collect and condense the rays of light upon the transparency in the lantern. The condenser most commonly in use has two lenses (Fig. 5, A and B). A is in form double convex, while B is meniscus, having its concave side set next the light. But the combination which concentrates the greatest amount of light includes an additional plano-convex lens. This lens (D, Fig. 6), placed close to the light F, collects a wider angle of rays than that taken up by B (Fig. 5), and consequently yields a larger and

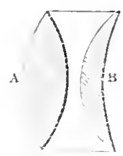


Fig. 5.—Two-Lens Condenser.

more luminous disc on the screen. It greatly depends, however, on the quality of the "objective" whether the light thus concentrated is turned to good account in the exhibition of lantern slides. Of the two sets of lenses employed in the lantern, the objective is the most important in its scientific functions. The condenser is used simply to collect and transmit the luminous rays, whereas the objective forms an enlarged image of the object placed in the lantern. Something has already been said about the image-forming property of the convex lens. This image is always inverted relatively to the position of the object, and its magnitude is to that of the object as its distance from the lens is to the distance of the object from the lens. This will be better understood by reference to Fig. 7. A B is an object

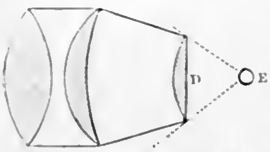


Fig. 6.—Condenser with Plano-convex Lens.

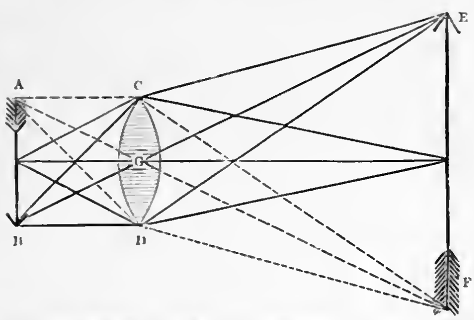


Fig. 7.—Illustrating Formation of Image as to Position and Size.

placed before a convex lens C D, every point of which sends forth rays in every direction. These rays are so concentrated in the lantern as to fall upon the lens C D (which we shall assume to be the objective), and are refracted to foci beyond the lens. These are at such a distance from the lens as may be determined by certain mathematical rules, which take into account the refracting power of the glass. The focus, where any point of the object is represented in its image, lies in the line drawn from that point to the object through the centre (G) of the lens. F will represent the upper end (A), and E the lower end (B), of the object A B.

In this way the image of an object may be formed at any distance beyond the lens, and on any scale of magnitude we please. But in order to render the image available for the purposes of the lantern, its magnitude must be limited to suit the intensity of the light by which the image is produced. In other words, it is possible to obtain an image of great magnitude by rays refracted far beyond the lens, but the light would be so diffused and enfeebled as to render the image almost invisible.

It is obvious, therefore, that an image of great magnitude can only be obtained by the aid of an intensely brilliant light, and of such lenses only as are fitted for the collection and transmissien of the greatest number of luminous rays.

In the lenses of this part of the instrument the objective combination should be even more carefully achromatised than those of the condenser, for this reason: an imperfectly corrected objective will curve and distort the lines in architecture, or produce an image perfect and distinct in the centre, and blurred towards the edges of the field.

It is generally conceded by experts that the achromatic combination employed in photographic portraiture may be used for the lantern with the greatest success, provided the focus is short, and the lenses of the best quality.

The "dissolving view" is hedged round with a charming mystery which it is almost a pity to dispel; but, as faithful chroniclers, we are bound to unfold the secret of this choice optical illusion. Dissolving may be effected in a variety of different ways. Of these, the most simple consists in having twin lanterns, one set above the other, as in the bi-unial apparatus, or placed on a plinth side by side, as in Fig. 8. "Dissolving" is effected in this

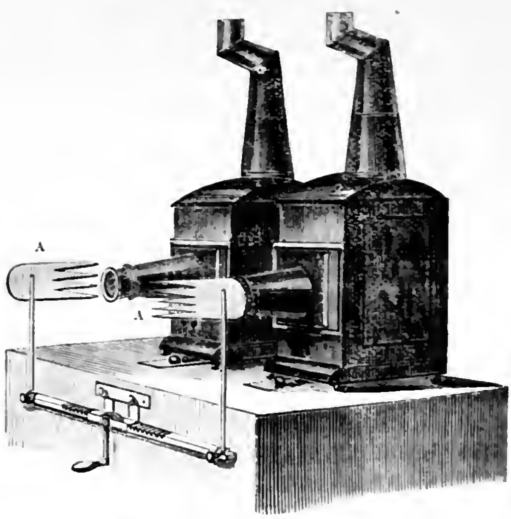


Fig. 8.—Twin Lanterns for Dissolving Views.

instance by the horizontal movement of the two combs A A; the light being supplied from oil-lamps.

In the bi-unial form the lime-light takes the place of oil, and dissolving is managed by alternately turning off and on the gas of one or other of the burners. By this means two most important ends are served. In the first place, the gas is economised, and, in the second, new pictures are made to grow out of the old by imperceptible degrees, until the series has come to a close.

Figure 9 sets before us the bi-unial lantern,

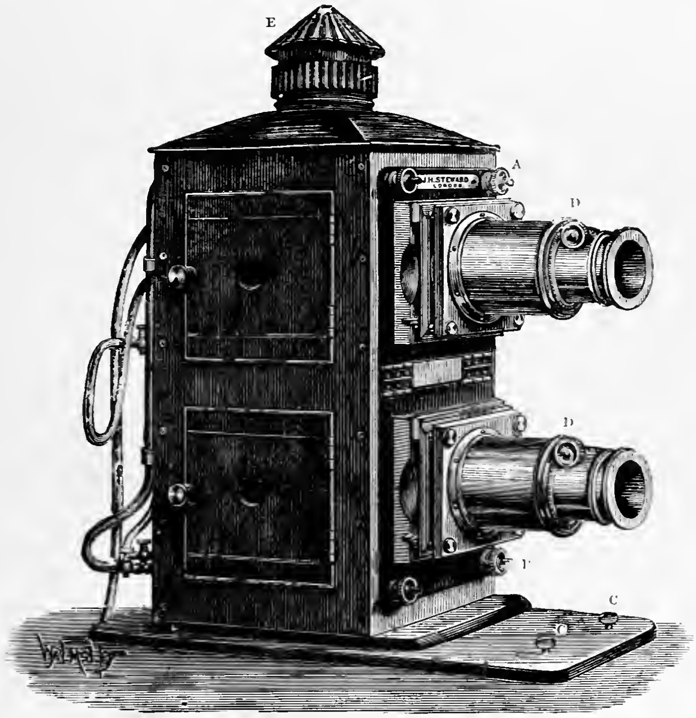


Fig. 9.—Bi-unial Lantern.

whose form must be familiar to our readers. It has figured in many a school-room, an angular mystery, manipulated by a maze of screws and milled heads, and accompanied by a pair of enormous dropsical-looking bags placed under heavy pressure. At the risk of losing some amiable readers in the maze of screws, pipes, and levers, we are in duty bound to state that they are all there for some useful end, and to describe their functions. Those at A and B are required to adjust the stages and the two luminous discs, so that they fall into the same space on the screen; C C are both employed for fixing the base of the instrument to its stand; D D are milled heads, each carrying a pinion fitted to racks let into the tubes, and by which the lenses are moved to and fro when focussing the image on the screen.

The body of the lantern is composed of polished mahogany, lined inside with thin plates of iron, while the twin stages in front are fashioned out of brass plates, and furnished with springs; these springs lend stability to the slides when placed in the lantern; they also press the slides against a plain surface provided for uniformity in focussing.

By disuniting the parts of this instrument, the chimney E and the apparatus in front may be reversed, and securely stowed within the body of the lantern, so as to save space in travelling.

There is yet a more complex form of magic lantern, fitted with a triple front, recalling a section of an old "three-decker." When the lenses are run out for action, few lanterns will compare with it in a popular entertainment. It mimics storms at sea and on land, with falling rain, floating clouds, and flashing lightning. It counterfeits sunset and sunrise, kindles cities into a conflagration, or buries them in the wreck of an earthquake or avalanche. In the hands of an accomplished manipulator, its resources are as manifold as they are wonderful—wonderful, when we come to examine the simple materials with which a lantern earthquake is produced. All that is necessary is three or four slides of the same subject in different stages of action, the one made to replace the other on the screen in succession so rapid, that the effect is as complete as it is realistic. It has happened that some of the younger members of an audience gazing on this illusion have clung to their seats, lest they too

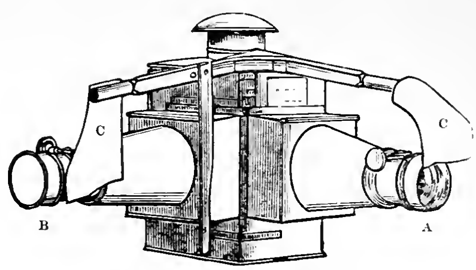


Fig. 10.—The Keevil Lantern.

should be included in the general overthrow. This triple-lens instrument is known as the Bridgeman lantern.

Another form of dissolving apparatus is the "Keevil patent." This consists of a single jet lantern, to which are fitted a double set of lenses at right angles to each other (A, B). The objective of one of these carries an achromatised prism, so adjusted as to project a second picture on the screen in the same position as the first. C C (Fig. 10) represents the shades employed in dissolving. The Rev. Canon Beechy exhibited a triple lantern constructed on this principle some thirty years ago. To him, therefore, we are indebted for the discovery. Fig. 11 introduces to public notice for the first time a lantern designed by the author for his own use. It possesses certain advantages, and is specially adapted for lectures where the subjects follow each other in an unbroken series. Mistakes arising from the insertion of a wrong slide, or an inverted subject, are apt to mar an evening's entertainment. But, as will be shown, errors of this nature are altogether avoided, and, by a simple mechanical arrangement, the slides present themselves in perfect order, and at their allotted times.

The instrument is fixed to the top of the packing-case B by the screws A A; the lid of the case (C) serves to elevate or depress the lantern, which may be fixed in position at any angle. Reared above the chimney are two metal uprights, secured to the sides of the lantern. These carry at their apex a wooden cube covered with fine leather; each side of this cube corresponds with the size of the slides. But, by the aid of strong ribbon binding, the slides are so united as to form a flexible band which traverses the cube and descends into the case B through slots D D. The cube turns on its axis E, to which is attached a milled head. The band is made so that the slides can be detached, and replaced by a new series at will.

The advantages of this simple arrangement are so obvious, as hardly to require further comment. The operator has only to turn the milled head of the cube in order to bring his subjects, one after the other, into position. This system might be applied also to the bi-unial apparatus, where dissolving views are required. The heat from the chimney is never so intense as to interfere, in any way, with the slides, while it clears them of surface-moisture, by which they might be obscured during cold weather.

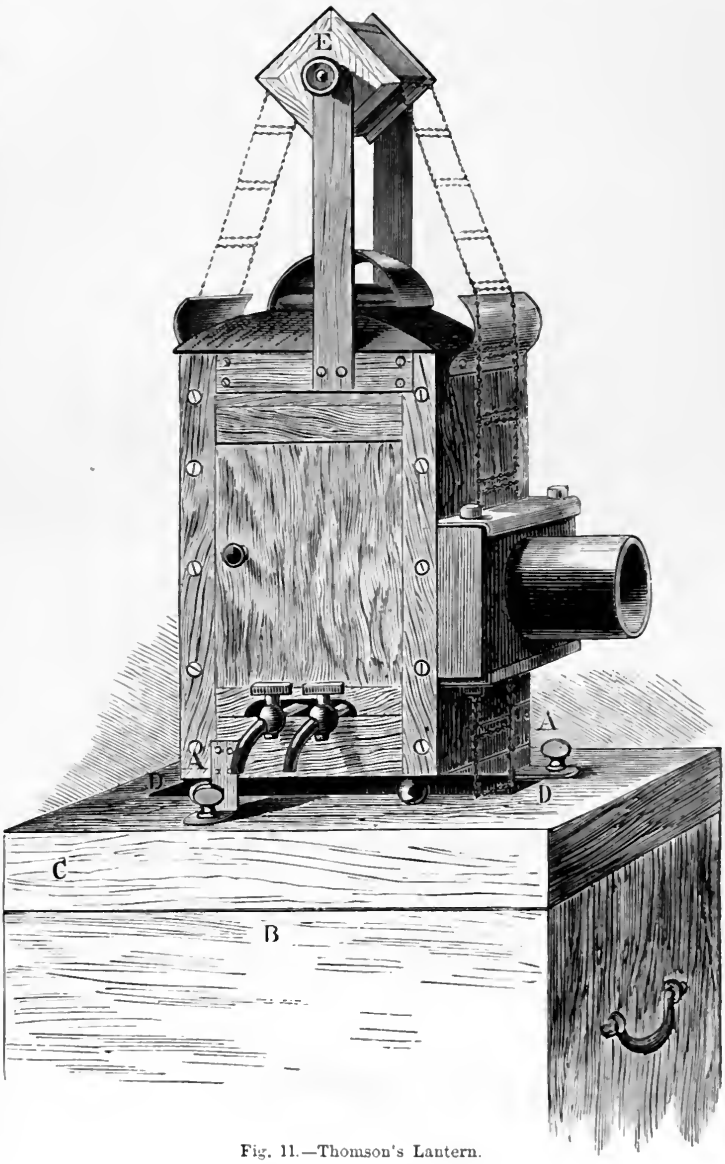


Fig. 11.—Thomson's Lantern.

Before dismissing the subject of the oxy-hydrogen lantern, it remains for us to describe briefly the accessory apparatus used in producing the light.

Ordinary coal gas may be successfully employed on all occasions in lieu of pure hydrogen. This may be either stored in a suitable bag, or supplied to the lantern through an india-rubber tube from an ordinary gas-jet. Oxygen gas, on the other hand, requires to be made from a mixture of one part of oxide of manganese to four parts of chlorate of potash. This compound is consigned to a retort, and the gas generated by heat.

Formerly, by reason of the rude mould of these retorts (some of them massive cast-iron bottles), rapid generation of gas, and closing of the outlet-pipes, accidents were not unfrequent, and some of them proved fatal to the gas-makers. Nowadays, however, retorts have been brought to perfection such as to render the making of oxygen a pursuit which may be carried on with comfort and safety in a drawing-room. The best retorts are connected with a metal bottle charged with water, through which the gas is passed and purified before entering the reservoir.

When the high-pressure jet and combined gases are employed, pure hydrogen is frequently used, and is generated in a specially-constructed vessel by the action of dilute sulphuric acid on the metal zinc.

It is unnecessary to enter into particulars regarding the numerous retorts in vogue at the present day. It is sufficient to state that in some of these the gas is made while the lantern is in use, while others—and these the majority—are only fitted for charging the detached air-tight gas-holder.

The lime-light gasometers used to be made after the fashion of the reservoirs of ordinary gas-works. These are almost entirely superseded by india-rubber bags, and by iron bottles. Into these iron cylinders the gases are compressed to about 300lb. per square inch, and are brought into action by the turning of a keyed stopper at A (Fig. 12). The

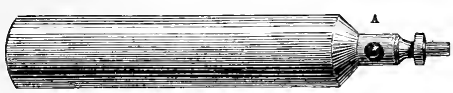


Fig. 12.—Iron Cylinder for storing Gas.

cylinders may be procured ready charged, and returned empty to the makers. They are cleanly, portable, and eminently satisfactory; but they ought to be tested before leaving the gas-works, and sufficient pressure of oxygen guaranteed. As a rule, they will be found perfectly trustworthy, and they are to be desired in preference to the great inflated gas-bags, and their still greater pressure-boards.

The bags are made of india-rubber cloth, and are fitted with stop-cocks, to which india-rubber piping may be attached. They are perfectly pliant, and may be stowed into a small space. When inflated for use, the bags are placed in the grip of great wooden jaws, weighted above, in order to impart the required pressure to the gas. Fig. 13 represents

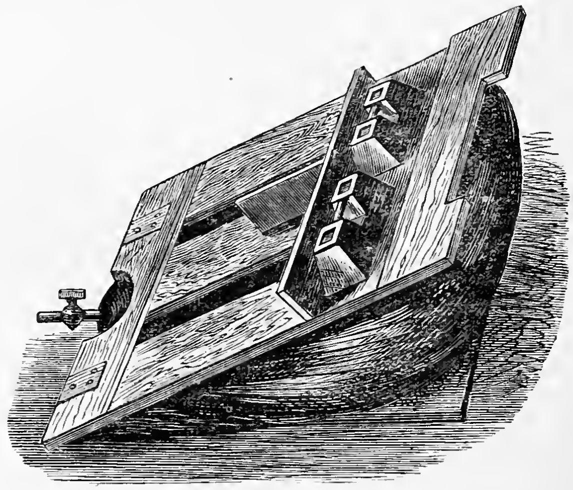


Fig. 13.—Gas Bag and Pressure-Boards.

the pressure-boards used for a single bag; but when the oxygen and hydrogen are both under pressure, another system of boards is super-added, making the whole apparatus as cumbrous as it is unsightly.

There are many accessories connected with the magic lantern which greatly enhance its scientific value, rendering it indeed "a lamp to the path" of the student. Take, for example, the microscope. The solar microscope was its forerunner, but, depending as it did upon the sun for light, it found a successful rival in the oxy-hydrogen lantern. When night has closed in around, and the curtains are drawn, the lime-light microscope unfolds to us a new world of organic and inorganic light. A drop of stagnant water magnified on the screen becomes an aquarium, teeming with living animalculæ. In the same way, a few grains of sand brought from the depths of the ocean are shown to be a group of shells of the most exquisite and delicate forms. It is, indeed, hardly possible to exhaust the store of objects, invisible to the naked eye, which may be shown to an assembled class of students. Nor do the educational powers of the lantern end here, for it may be successfully applied to illustrate the phenomena of polarised light, of the spectroscope, of the formation of crystals in chemistry, and of the ever-changing designs of the kaleidoscope.

A PRIMROSE.

By Robert Brown, F.L.S., etc.

Reckless of law, oblivious of Royal Commissions, we are about to commence a vivisection. The instruments are on the table before us, and the victims are growing in a patch under our window. The first consist of two triangular or glover's needles, pushed into two bits of wood as handles, a razor, a pair of forceps or tweezers, a lens or magnifying-glass, a pair of small, sharp scissors, a few slips of glass, and a microscope close by in case of emergencies. The subject for our vivisectory studies is nothing more serious than a primrose, and the object of our "research" is the structure of a flower. We have selected the primrose, not because in this humble flower there is anything remarkable or typical, but merely because it is so very common, and, in springtime, the easiest to be had. We do not propose "dropping," as did the "literary man" of "the Golden Dustman," into "poetry," otherwise—so industrious have been the songsters of the primrose—a volume of this work might be filled with the verses in its honour. The botanist must be a very Gallio to all of these things, and study the plant for what it actually possesses, not for what a more or less vivid imagination may attribute to it. Yet, even then he will discover in it beauties, and mysteries, and wonders, such as the poet, who only looks on it æsthetically, never dreamed it to possess. To Wordsworth's Peter Bell

"A primrose by the river's brim
A yellow primrose was to him—
And it was nothing more."

But if, as Professor Huxley somewhere remarks, Peter had been told that it was a corollifloral dicotyledonous exogen, with a monopetalous corolla and a central placentation, it would not have aroused him a wit from his apathy. Pursuing his encyclopaedial chant, the Cumberland clown would have further discovered that the familiar "primrose by the river's brim" was the *Primula vulgaris* of Linnaeus, and that it belonged to the order *Primulaceæ*, a family which also numbers in its ranks the *Cyclamen* or sow-bread, the *Anagallis* or pimpernel, the *Samolus* or brook-weed, the *Trientalis Europæa* and the *Dodecatheon* of our gardens, and that this familiar but most beautiful of spring flowers has for its near relatives the bird's-eye and Scottish primroses (*P. farinosa* and *Scotica*), the cowslip (*P. veris*), the *Primula elatior* or ox-lip, and between two and three hundred other less-known plants. Moreover—is it not written in the books?—the plant before us has oblanceolate wrinkled radical leaves, a syncarpous superior pistil, pentandrous stamens, and an inferior gamosepalous calyx.*

To us it is immaterial what names pedants have applied to the objects before us. It is for us to see them, and accept just as much or as little of that terminology as may suit our purpose, and it will be found that wonderfully little will suffice. Taking, then, a general glance at the flower, we see that it is on the top of a long flower-stalk, is surrounded by a green outside covering, within which is the coloured envelope which we usually call the "flower," though in reality it is one of the least essential parts of any flower, and is frequently entirely wanting. Inside this, again, is the third whorl of organs, but we can only see the tops of these peeping out from the tube of the coloured envelope. Finally, on looking carefully down the tube after parting the brown tips which appear, we may catch a glimpse of the summit of a fourth organ, which, in reality, is the most important of all. This is about all we can see by a casual observation of the primrose before us. We must now commence to dissect it. In dissecting even a flower there is, however, a right way and a wrong way to do it; and the wrong way is to tear it to pieces with the fingers. The right method, though the slower, is to slit the outer covering on each side from below upwards with one of the needles; then cut off the one half with the scissors, and do the same by the second or coloured envelope; then, if the tyro possesses sufficient manual dexterity, the razor may be used to split down the innermost organ; if not, this can be done at a later stage of his work. In this way we shall obtain a "vertical section" of the flower; or, in other words, we shall have cut it down the middle (Fig. 1).

The flower-stalk, or *peduncle*, corresponds to the leaf-stalk of a leaf. It is covered with the general skin of the whole plant, and thickly clothed with hairs which, we have already seen (Vol. I., p. 338), are mere cells elongated, though often very beautiful. The stalk itself, as a very thin slice made by the razor and laid on a slip of glass under a good

* Dr. Andrew Wilson's "Leisure Time Studies," p. 33.

power of the microscope will show, is composed of cells or little bladders containing various juices all placed side by side, or with minute intervals between them which permit of the circulation of air. There will also most likely be cut across a few delicate vessels which may either contain air or convey the nutritive juices which the flower so much requires during the exhaustive process of flowering. In some plants these vessels are very numerous, and the flower-stalk, of course, proportionately tough in consequence. In others the vessels contain a little thin spiral coiled up inside them, not unlike the wires which are occasionally put inside india-rubber tubes to keep them from closing and yet give them the necessary degree of flexibility. These spiral tubes* can be very well seen in the common hyacinth which flowers about the same period as the primrose. When the flower-stalk of one of these plants is broken across and held up to the light, a glairy, cobweb-looking thread will be seen between the two broken pieces of the stalk if it has not been too rudely sundered. The flower-stalk is not absolutely essential to the life of the flower, for, like the leaf-stalk, it is often wanting. The green outside cup, or *calyx*, is made up of five leaf-like organs, joined together by their edges so that they form nearly one single covering (Fig. 2). In many plants—the wall-flower for instance—these divisions of the calyx (*sepals*) are perfectly disunited one from the other. The calyx is usually green, as in the primrose, but in other plants, such as the fuchsia and the tulip, it is more or less coloured (Fig. 3).

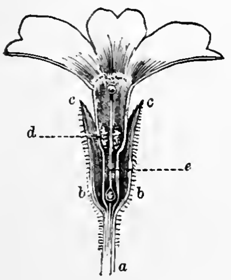


Fig. 1.—Flower of a Primrose (*P. vulgaris*), divided longitudinally, showing (*a*) Peduncle, (*b b*) Calyx, (*c c*) Corolla, (*d*) Stamens, (*e*) Pistil.

If we gently pull off the calyx, it will be found that the epidermis or skin of the peduncle comes along with it, so that the peduncle can be literally flayed. This affords us an opportunity of putting a bit of the epidermis, with the aid of a drop of water, on a slip of glass, then flattening it down with a thinner piece, such as is used to cover microscopic slides, and examining it with higher magnifying power than the hand-lens. If the same course is taken with the skin of the calyx, it will be found that both contain stomata,† and that their epidermis is, especially that of the calyx, in every respect like that of the leaves.


Fig. 2. Calyx of Primrose.

We now come to the coloured covering. Like the one immediately outside of it, this envelope is made up of five pieces, each piece a little notched at the tip, and the pieces united throughout their lower extremities, so as to form a tube. In many plants these parts (*petals*) of the coloured envelope (or *corolla*) are separate, and in many others, like the sweet pea, are irregular in size; that is to say, the corolla is lop-sided, as in similar cases the calyx is. Again, in some plants the corolla falls off at an early date in the history of the plant, just as the calyx does; for example, in the buttercup. In the *Escholtzia*, or extinguisher flower of California, now so common as a bedding-out plant in our gardens, the calyx is in the shape of a yellow-coloured "extinguisher," which must fall off to allow the flower-bud to expand. In the primrose, however, the corolla remains during the life of the flower, as does also the calyx. The calyx, we have seen, was composed of little leaflets, in their structure identical with leaves; so, in like manner, the anatomy of a petal is also a modification of the anatomy of a sepal. It occasionally even happens that the corolla is green, but black is a hue which it never obtains; what is usually so called (for instance in *Pelargonium tricolor*) being only a purple—red, blue, or deep brown. But as a rule, the corolla is gaily coloured, the colours being blended in that inimitable manner which gives the beautiful variety to flowers. Now, what is the use of the corolla and the calyx? What is often wanting cannot, one would think, serve any remarkable or essential purpose in the economy of plant life; and looking at the corolla from this point of view, it is, though the most beautiful, yet the least important of the floral whorls. In the whole of the great division of plants called "monocotyledons," to which grasses, sedges, the iris, the orchids, the tulip, and a vast


Fig. 3.—Longitudinal Section of the Flower of a Fuchsia (*F. splendens*, Zucc.).

* "Science for All," Vol. I., p. 296.

† "Science for All," Vol. I., pp. 21, 97.

array of other plants belong, the corolla is wanting, the bright-coloured organs usually so considered being proved, by various circumstances, to be the calyx. And, as a general rule, we may say that it is too delicate to serve as a protection to the essential organs within, unless, indeed, where, as in the vine, the calyx is so small that it has to supply its place in this respect. There is, however, little doubt that when there is honey, or other sugary liquid, at the bottom of the flower, by attracting insects to it, it serves —as we shall see in a future article —a most important purpose in the economy of Nature.

Fig. 4.—Stamens of Wallflower (*Cheiranthus cheiri*).

Before cutting away the corolla, examine the part just below where the petals unite to join the tube. On each petal, supported on a very short stalk, is a small, brown, longitudinally-grooved organ, pointed at either end, and shaped not unlike a weaver's shuttle, but not bigger than a large-sized needle's eye. As there are five petals, there will be five of these *stamens* to form a circle round the tube, which can be seen peeping up when the flower is looked into. Many stamens are supported on long stalks, as in the case of the fuchsia, wallflower, poppy, or the blue-bell (Figs. 3, 4, 5, 9), while in other cases they are altogether devoid of *filament* or stalk. The filament when present is usually a thin stalk, though sometimes, both in form and dimensions, it simulates the petals. Generally, each filament is separate from the other; but cases are common in which all of them are united into one bundle, forming a sort of tube, as in the loose-strife, lupines, flax, &c., or into several of these bundles. Surmounting the filament, or present whether there is a filament or not, is the essential portion of the stamen viz., the *anther*, the brown seed looking body which we see on each petal of the primrose.

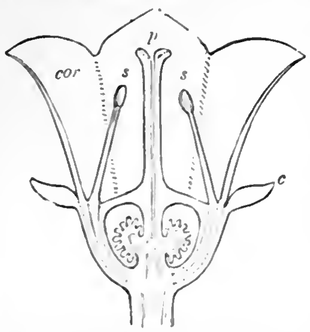


Fig. 5.—Vertical Section of the Flower of Blue-Bell (*Campanula*).
(*c* Calyx; *cor.* Corolla; *s* Stamens; *p* Pistil.)

The anthers are each made up of two lobes, or pouches, united by a delicate tissue, the "connective," which may be described as the prolongation of the end of the filament. This double character of the anther can easily be seen, even with the naked eye, in those of the primrose lying before us; but if the anther of a grass-flower is examined, this will be observed even more perfectly. In this latter case, the connective does not run the entire length of the anther. Hence the two sides or pouches separate towards their ends, giving the anther the "bifid" appearance characteristic of it in grasses, &c. A very limited study of the anthers of different plants will form an instructive lesson in their endless variety, shape, form of union, number, colour, mode of opening, and so on; but if any one is cut across, the structure, as seen in a very thin slice, examined in the usual manner under the microscope, will be found something like this (Fig. 6). Like the filament and all other parts of the plant—with one exception, which we shall presently meet with—the anther is covered externally with the general plant-skin or epidermis, often pierced with stomata. Inside this is a layer of curious fibrous cells, which give the anther the elasticity necessary for its bursting and distributing the pollen which it contains, and which is developed inside the pouches, and sometimes even aids, as in grasses and lilies, in turning the anther inside out.

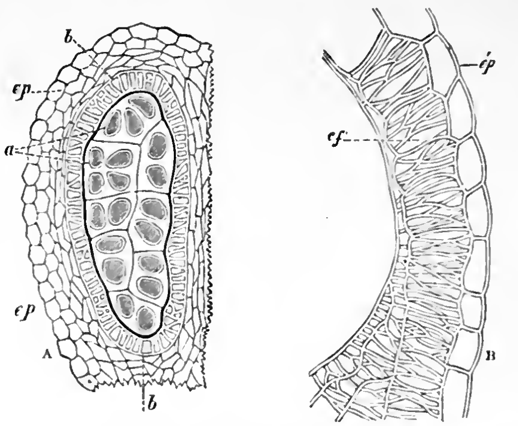


Fig. 6.—Anther, cut Across.
(A) General Section showing Pollen-Grains in the Pouches; (B) Coats of Anther more highly magnified. (*ep*) Exothecium or Outer Layer (Epidermis); (*bb*) Endothecium, or Inner Layer (fibrous Layer). (*a*) Pollen-Cells with Grains of Pollen; (*cf*) Layer of Fibrous Cells.

Even while we have been working, the slip of glass on which we have laid the anthers has got sprinkled with a fine brown dust, which has fallen out of them. If we walked through a field of grass in which the grasses have been allowed to flower, our shoes would get dusted whitish with a similar powder, and if the lawn from which these primroses were gathered had been badly kept,

according to the gardener's idea, and well after the botanist's liking, the anthers of rib-grasses and other weeds would, in like manner, have emptied their contents on to our trousers and shoes. This dust is the *pollen* or fertilising dust, about which, on a future occasion, we shall have much to say. It is developed inside the pouches of the anther, and when ripe is —speaking generally—discharged in various ways on to the top of the innermost organ of all. With the naked eye, or with the lens, we can make very little out of it—it looks simply like dust; but under the microscope it takes an entirely different and more interesting aspect.

It will then be seen to be composed of an infinite number of little grains more or less rounded. Each of these grains is composed of an exceedingly delicate envelope, which, in its turn, may be divided into two layers or vesicles, one within the other, and so closely attached that the fact of their existing must be taken by the reader on the authority of the writer, as it is difficult, unless with good appliances and considerable experience, to make them out. The outer one is comparatively thick and resisting, but with little elasticity, so that it breaks easily when distended, and is often granular or fleshy in appearance. It is, in fact, an exudation from the inner one, which is thin, but of considerable toughness. Inside is a glairy liquid filled with minute particles, and known as the *fovilla*. This fovilla plays an important part in the history of the seed; but, meantime, what we may note about it is that the fluid makes curious and apparently spontaneous movements, or, at all events, these movements are stimulated by no cause which we have been as yet able to detect. The pollen-grains, though invariably of the nature described, are not, in all plants, of the same shape as those which we have described (Fig. 7). In general they are roundish, but in the chicory they are many-sided or polyhedral. In *Basella rubra* they are square; in *Tradescantia*, a common garden plant, cylindrical; in musk, spirally grooved or ribbed; in hollyhocks, covered with little eminences, so that each grain looks like a miniature sea-urchin; and so forth. The size of the grains also differs considerably. In the sweet-potato plant they are large, in the forget-me-not and india-rubber they are exceedingly small; and they differ in size even in closely-allied plants. In the fir-tree order and some other plants, the pollen-grains are not simple cells, as in other species, but are composed of three or four blended together by viscid or elastic material, so that in the evening primrose, *Clarkia*, &c., each grain is triangular in shape. Again, in heaths, each grain is composed of four ordinary ones united; in several acacias there are sixteen, and in other plants a smaller number united. In the eel-grass, or *Zostera*, a true flowering plant, which on some parts of our coast, but more especially on the shores of the Baltic, may be seen waving in banks in the sea, the pollen-grains consist of long, slender threads, divested of the outer coat, and look, as they lie in the single pouched anther, not unlike a skein of silk. Finally, in the milkweed and orchid families, the pollen is generally solid—that is, a great number of grains are united into pear-shaped masses, like those sketched in Fig. 8.

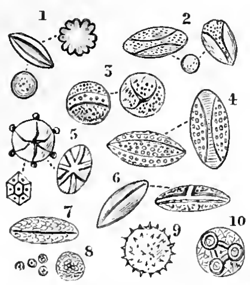


Fig. 7. — Figures of different Kinds of Pollen-Grains.
1. Primrose; 2. Auricula; 3. Anemone; 4. Iris; 5. Clematis; 6. Tulip; 7. Rose; 8. Buttercup; 9. Hollyhock; 10. Passion-flower.

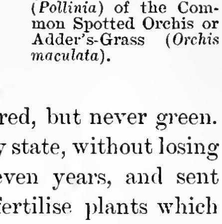


Fig. 8. — Pollen Masses (*Pollinia*) of the Common Spotted Orchis or Adder's-Grass (*Orchis maculata*).

The colour of pollen is generally yellowish or brownish, as is that of the primrose; but even among plants of the same "genus," such as different species of lily, all shades from yellowish to brown might be found. It is often white, occasionally bluish, sometimes red, but never green.

Pollen may be kept in the dry state, without losing its vitality, for months and even years, and sent from country to country to fertilise plants which produce only female flowers. For instance, the date-palm is "diœcious," that is to say, the stamens are on one plant, and the pistil (the innermost organ) on another—a by no means uncommon arrangement; and accordingly, from the earliest periods, it has been the custom for the Egyptians to bring branches with stamen-bearing flowers from the desert, to fertilise the others with pistils on the cultivated trees. In 1808, owing to the occupation of Egypt by the French, the inhabitants were prevented from obtaining the branches of the "male" flowers; and the result was, as only "female"-flowered trees are cultivated, no dates were produced. The pollen will also be wafted long distances by the winds, as the so-called "sulphur-showers" in the vicinity of fir-forests prove. In 1505 it is recorded by the poet Pontanus—

and by even more credible witnesses—that a date-palm at Brindes, which had never produced, was fertilised, and in consequence matured fruit, from the pollen wafted thirty miles from another tree of the same species at Otranto; and date-trees in St. Helena have been fertilised by pollen obtained from trees on the continent of Africa. Numerous similar cases are on record.*

Before leaving the stamen, we may direct a glance at the way in which the pollen is discharged from the anther. In the primrose we see it opening its whole length along the line of middle furrow, and thus freeing the fertilising dust; but if we examine a blaeberry (*Vaccinium*), the winter-green (*Pyrola*), or the ordinary potato-flower, it will be seen that this is effected by the opening of a pore at the tip of either lobe. Again, in the laurels, barberry, &c., the anther opens by two little valves like trap-doors on the side, more or less to the inner face; while, in one small division of plants, the pollen escapes by a transverse opening which allows the top of the anther to be lifted off like a lid. We now snip off the corolla with the attached stamens, which have supplied us with the text of the preceding discourse, and find exposed to view the innermost organ of all—viz., the *pistil*. In the plant before us, it appears as a straight, mast-like organ, swollen at the top and surmounted with what looks like the "truck" of a mast. It is placed on the top of the flower-stalk, which is a little expanded in order to afford room for the attachment also of the corolla and the calyx, though nothing like to the extent it is in some plants in which the stamens also are attached here. Indeed, in the strawberry the juicy portion which we eat is not really the fruit, but merely the swollen upper part of the flower-stalk, the real fruit being the hard, seed-like bodies scattered over the surface of the edible part. In like manner, the fleshy part of an apple is really the calyx swollen and thickened, the calyx remaining on the top of the fruit. Looking, then, at the pistil, we see it is naturally divided into three parts: the lower swollen portion, or *ovary;* the middle part, or *style;* and the upper more or less expanded summit, or *stigma*. The style is not always present, an example of which deficiency is found in the poppy, where the stigma rests immediately on the top of the ovary (Fig. 9).

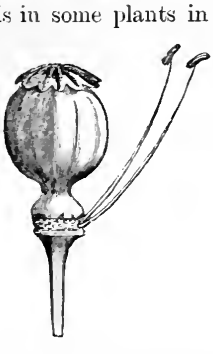


Fig. 9.—Pistil of the Poppy, showing Stamens inserted on the Top of the Peduncle and Stigma on the Top of the Ovary, without the intervention of a Style.

* Brown: "Manual of Botany," p. 347.

Should the reader be more skilful at manipulation than most unpractised microscopists are, he will find it a useful exercise to try and dissect the covering of the ovary from the contents of that sac. Should he succeed, he will find something like what is figured (Fig. 10).

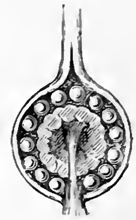


Fig. 10.—Placenta of Primrose, with attached Ovules—the Walls of the Ovary detached.

A central "cellular" pillar, a prolongation from the bottom of the ovary, runs up the middle of that cavity, and around it cluster a number of somewhat rounded little bodies. The pillar is the *placenta*, and the bodies which it supports are the *ovules* or "little eggs," the germs of the future seeds, and of course of the future plant which the seeds perpetuate. If we cut the ovary across—*i.e.*, in technical language "make a transverse section" of it—the simplest of mechanical operations—we shall see the nature and relation of the placenta and its ovules even better (Fig. 11). A longitudinal division of one of these ovules (Fig. 12), shows that it is covered with three distinct coats, uniting below and open at the top, while the interior is occupied by a bag containing fluid. In this interior space is developed the future plant, after the pollen-grains have come in contact with the stigma—a subject for after explanation—and when in the fulness of time the ovule has grown into the seed.

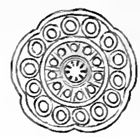


Fig. 11.—The Ovary of the Primrose cut across, showing Placenta, with Ovules and the surrounding Wall of the Ovary.

The style, when present, is composed of a loose tissue, the use of which will be seen when, by and by, we examine the act of fertilisation. The stigma is the glandular apex of the style, or (as we have seen), if the style be absent, is placed on the top of the ovary. It is the only exposed part of the plant not covered with epidermis, and secretes a viscid material, which is more abundant at the time when the pollen is ready to fall on it, and therefore doubtless serves a good purpose, not only in retaining the pollen-grains, but

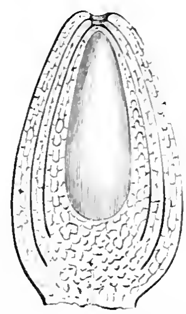


Fig. 12.—Longitudinal Section of an Ovule. That of *Polygonum* (the Knot-grass) has been taken in preference to the Primrose, as being clearer in Structure.

also in causing the protrusion of those "pollen-tubes" which we shall by and by learn are so essential to the conversion of the ovules into seeds capable of reproducing the plant.

Having thus briefly dissected the different portions of a flower—and though in all plants the structure is generally the same, in none is it identical—we may now look for a moment at the symmetry of the flower. Supposing a complete flower of the primrose cut across—though the facts we wish to bring out can be seen without this operation—the following would be what would be displayed in a diagrammatic manner (Fig. 13).

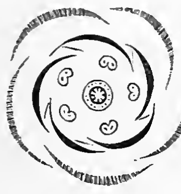


Fig. 13.—Diagram showing the Symmetry of a Primrose Flower.

It will be seen that all the parts alternate with each other—that is, the parts of one whorl are opposite, not those immediately contiguous to it, but the one before or after—so that if the different whorls of a flower could be pulled out, the phyllotaxis (p. 7) would be very like that which prevails in the arrangement of the leaves on stems.

In the primrose we do not see the *nectaries* or glands at the base, which secrete the honey for which the "busy bee" flies about from flower to flower, unconsciously performing work in return for the meal which Nature has spread out inside the corolla in order to tempt it; but this can be observed in many of the plants which are springing up in the same meadow with the primrose. The various colours also which paint the corollas of the different flowers are an interesting study. The pigments lie in the cells of the petals, and like everything else in the plant, are elaborated by the mysterious chemical processes going on in the living laboratory which they ornament. The odours, in like manner, are due to the presence of essential oils or other glandular products which are developed in the cells of the epidermis. Many of these oils have defied the skill of the chemist to seize and make them his own; nor are the operations which cause their exudation very clearly understood. Some flowers, like the primrose, yield their delightful odours through life, day and night, while others are grateful to the nostrils only at night; nor are the same odours common to several closely allied plants. For instance, the smell of hay is common to a grass, the woodruff, the mililot, and all the varieties of a species of orchid. Again, some flowers only exhale their fragrance early during flowering, while in another class it is given forth only at particular periods. Between the smell and colour of plants there is some analogy. For instance, the Indian chrysanthemum agrees faintly in scent, as it does in colour with the common wall-flower. White flowers have the greatest average of pleasant smelling ones; orange and brown flowers are often disagreeably scented; while the family of plants which has the greatest number of odoriferous flowers is not—as might be supposed—the order of roses, but that of water-lilies.

Finally, before closing this brief study of the anatomy of a primrose, let us say a few words about the nature of the different parts of the flower. It is a characteristic of Nature to be profuse in the adaptation of the same object for different purposes, but economical in the use of materials. For instance, we have seen how every portion of the plant is primarily made up of cells, and that even at the most mature stage, cells or vessels—or, in other words, cells of different form—make up the whole plant. It would have been easy for the Creator to have made the root of one substance, the stem of another, the leaves of a third, and the flower of a fourth. But this is not the case. So, equally, do we find that while the organs of a plant are infinitely varied in different species, they are all on the same model, and some are even transformations of the other. Take, for example, the parts of the flower. All of these are modelled on the leaf. The sepals, it requires but a slight insight into vegetable forms to see, are merely leaves in shape and structure. The petals are a little removed from the leaf form, but yet are essentially coloured leaves in shape and structure, and even in function. In the water-lilies the formation

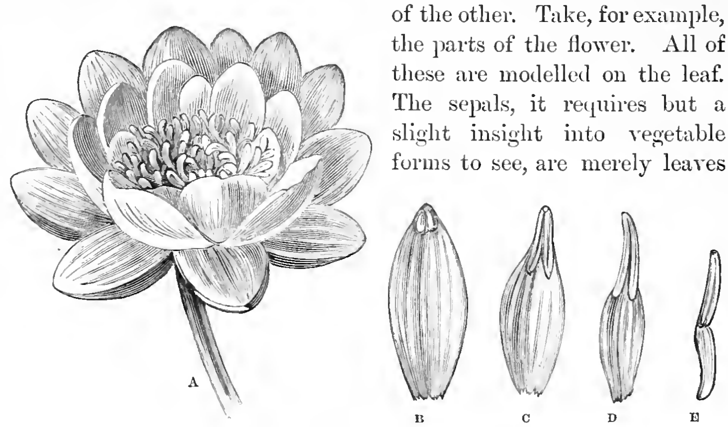


Fig. 14.—White Water-Lily (*Nymphæa alba*).
(A) Entire Flower; (B C D) Forms through which the Petals B C D (each of which bears an Anther) pass, to the State of the Normal Stamen E.

is indeed so gradual that it is sometimes difficult to say where the change takes place (Fig. 14). The stamens are very unleaflike organs; yet in this plant the stamens can, in the outer part of the flower, only be detected to be such by the fact of their possessing anthers on their tips. Adopting one of the many theories put forward, we may consider the connective, or substance which connects the two lobes of the anther, as the medial nerve or midrib; the lobes of the anther are the two sides of the leaf, each rolled towards the midrib; the under-surface of the leaf is therefore the outside, and the upper surface of the interior lining of each the pouch, while the epidermis and nerves are not developed on the inside; the pollen is therefore formed from the soft tissues of the leaf, and the filament, when it is present, represents the leaf-stalk of a leaf which has such a stalk; when it is wanting, then the leaf type may be supposed to have been a stalkless leaf. A double flower is merely one in which nearly all or part of the stamens, and the pistil, have become converted into petals; hence, such flowers cannot, owing to the absence of the essential organs, produce seeds.

In the white-flowered garden peony there is a gradual transition from the compound much-divided leaves of the stem, to the white or rose-coloured petals of the corolla. In the *Camellia* there is also a gradual passage from sepals to petals, and the same may be seen in many other flowers. The pistil at first sight seems the widest divergence possible from the leaf type. But in reality it is, like the other floral organs, a modified leaf. In the primrose we do not see this so clearly as in some other plants, because in the primrose the division walls inside the ovary have disappeared—got broken up and absorbed in progress of growth—so that when it is cut across, the component parts do not so readily discover themselves. In reality, the ovary is usually made up of two or more "carpels"—each with its style and stigma—which carpels are simply leaves bent from edge to edge, and arranged in a circle, more or less united; in the axils of these, among other modifications, the ovules, which may be considered buds, are placed, and the styles are prolongations of the tips of the leaves, the stigma being a cellular expansion at the top (Fig. 15). This may be theory, but it is a theory which lies at base of all scientific botany. By an extensive study of plants it can be shown to be true, and often when least expected Nature unveils her secrets.

Fig. 15.—Pistil of Meadow Saffron (*Colchicum*), consisting of three Carpels, each a bent Leaf with the Ovules on their Edge.

In some diseased conditions of the plant, or when its constitution has been disturbed by cultivation or some other circumstance abnormal to it, the petals will return to leaves, the stamens to petals, and even the petal to the original type. This latter state is not unfrequently seen in double flowers, such as the double-flowered cherry. In the strawberry a common monstrosity is for all the floral organs to revert to the sepals or imperfect leaves of a green colour. It is from such facts as these that botanists are led to the irresistible conclusion that the leaf is the *type* on which all the parts of the flower are formed, and that they only differ from the ordinary leaves on the stem in their special development. In an early stage of their growth they all look alike, though it must not be supposed that a petal, for instance, though called a "metamorphosed leaf" had ever actually been a green leaf, and that the stamens, and the pistil had ever existed in the state of foliage. All we mean by the phrase is that they are fundamentally one and the same organ, and as in the early condition of the plant they cannot be distinguished one from the other, so in a later stage of growth they keep up a family likeness, though this likeness is concealed from all save those whose duty and whose pleasure it is to study such physiognomies.

A CANNON SHOT.

By C. Cooper King, Captain R.M.A., Royal Military College, Sandhurst.

THE art of gunnery may be regarded as having two principal branches, the one dealing with the construction and manufacture of the weapon, the other with the nature of the projectile and the laws that govern its flight. To separate them entirely is difficult, if not impossible, for they each act and re-act upon the other. The gun is but the tube whence the shot is fired and whence it obtains its velocity and direction, but it is the shot that does the actual work; and the best gun would be worth little if its projectile failed to strike the mark or to penetrate the object aimed at with a sufficiently destructive effect.

Neither gun nor shot can be alone considered of paramount importance. An excellent gun may fire a shot which would have neither range nor accuracy, owing to its faulty form. A less powerful weapon may make better practice, because its missiles are suitable. Still, range and general accuracy of direction are mainly the gun's business, the actual work to be done upon the enemy or his defences that of the shot.

In examining what a shot should be and what it ought to do, there are two sets of considerations, which must be dealt with separately. First, before it leaves the gun there are the influences the gun and powder may have on it, together with that which its actual form may have on its flight; secondly, after it has left the gun there are the effects of the various retarding forces it meets with, and the character of the work it is required to do when it reaches its sphere of operations.

First of all, it is well known that the inner tube of the gun may be plain or rifled. In the former case it is loaded from the muzzle with a spherical cast-iron or steel projectile, which might strike on any side after it was fired. In the latter case it may be loaded from either breech or muzzle, and the shot is elongated, so that to get its full effect it must strike point foremost.

Now, in all muzzle-loading guns, whether smooth-bore or rifled, there must be a small space between the shot and the bore, which is represented by the difference between the area of the cross section of the projectile and that of the bore. This is called "windage," and is necessary to facilitate loading by permitting the escape of the air in the gun, and to prevent accidents resulting from the jamming of the shot owing to dirt or inaccuracy of form. But it has another advantage, which is claimed for it in all muzzle-loading systems. By far the most deadly of the projectiles fired by cannon are "shells," or hollow shot filled with powder, which is ignited at a certain period of the flight by the "fuzes" which close their only apertures. The simplest form of fuze is that which is fired by the explosion of the charge; and where windage exists the powder-flame can pass round the shell and ignite the fuze. Where windage does not exist, the fuze must be self-acting, and must be ignited by means of internal mechanism; but these are liable to deterioration from climate and other causes, as well as being complicated in construction and expensive to manufacture. But though windage is unavoidable in all muzzle-loading ordnance, and is even of use when "live" (filled) shells are to be fired, its disadvantages are great. The escape of the powder-gas, which has, by so escaping, done no work on the shot, necessitates larger powder charges, in order to insure that sufficient gas shall be generated to produce the required velocity. The destructive effect to the bore of the gun by this rush of flame over the projectile is considerable, and is known as "scoring;" but, as may be imagined, it is greater on the upper than the lower surface, though the whole suffers more or less. In smooth-bore guns, where the charges of powder, which are relatively small, burn rapidly, and the shot is easily moved, owing to its form, the damage done to the bore is slight; but the vent or channel by which the cartridge is fired is so speedily worn that, though lined with copper, which has the property of toughly resisting the burning effect of the gas, it has to be frequently re-lined or "re-bouched."

In rifled guns, where the charges are considerably heavier, and the projectile, owing to its weight and shape, is not so ready to move, let alone that great resistance is offered by the rifling into which it is forced, the time during which the gas is able to act upon the bore is longer, and the destructive effect proportionately greater. In fact, guns that have fired many rounds are so deeply scored and fissured that a casting in gutta-percha of the lower part of the bore resembles the rough and rugged bark of an oak-tree, and the gun has then to be re-lined or re-tubed. To some extent this has been obviated latterly by the use of the "gas check," which is attached to the base of the shot, and which

is intended not entirely to prevent the flame from reaching the fuze and igniting it, but to partially destroy the windage and fill the bore before the mass of powder-gas has time to be developed.

This scoring is peculiarly destructive to bronze guns; so much so, indeed, that the use of the ordinary soft alloy has been abandoned as a material for ordnance. It is apparently impossible to make it completely homogeneous, and when cooling the tin seems to separate from the copper and form white spots, called "tin spots," which are peculiarly susceptible to the action of ignited powder. Bronze cast under pressure and chilled during the operation, according to the method adopted by General Von Uchatius in Austria, offers better results, and in some respects possesses many of the properties of steel; but very little faith is placed in this metal in England, for many other reasons besides that of being easily injured by scoring.

But windage has also a direct effect upon the shot itself. In rifled guns it is essential that the projectile should be so "centred," when it is passing through the groove, that its axis and that of the gun should be as nearly as possible coincident. If this be not the case the shot will "wabble" on leaving the gun, and its accuracy will be materially affected. With much windage centreing is difficult. In smooth-bore guns the passage of the gas, owing to this cause, has two effects. First, it causes the shot to rotate on one of its axes, by moving the upper surface in its passage, while the lower surface resting on the bore is retained there by friction and its own weight. The direction which this rotation has on leaving the piece may cause its flight to be irregular. To this may be added the unavoidable want of homogeneity of any cast shot, owing to which the centre of gravity of the mass and the centre of the figure do not coincide, which is a fruitful source of irregularity of flight.

Next, the shot has a tendency to rebound after the first pressure downwards of the gas, and the last rebound it makes at the muzzle would influence its final direction. Thus, in Fig. 1 the shot would

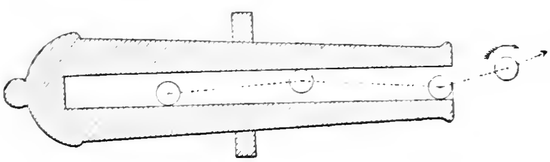


Fig. 1.—Illustrating Effect of Windage upon Flight of a Shot.

have a tendency to deviate to the left: a tendency still further increased if the rotation of the shot chanced to be towards the same side. These two sources of error—irregular rotation and rebound—are the chief, though not the only, causes of the inaccuracy of smooth-bore guns.

Now, the object of rifling is to get rid of these errors first of all. The regular rotation of the projectile tends, as will be seen later, to equalise the pressure of the air on it during its flight, as well as to insure that the rotation should be always acting in the same direction. Rebound becomes impossible, as elongated projectiles can be employed; and these have the further advantage of giving a heavier shot or larger shell for the same diameter of bore, while heavy missiles have more momentum and are less affected by external forces than lighter ones.

Many methods have been devised for producing this rotation, but they all group themselves under three heads: (*a*) the mechanically fitting; (*b*) those in which the shot have either studs to fit the grooves, or a soft metal base which is expanded into them by the first action of the powder-gas; (*c*) breech-loaders, the shot for which have an outer covering of soft metal, rendering them slightly larger than the bore, which is compressed by the gas into the grooves.

Of the first kind, the Whitworth gun (Fig. 2), with

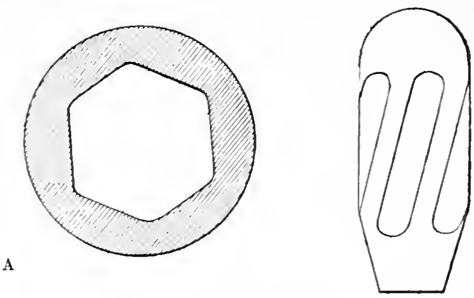


Fig. 2.—Whitworth Gun.
(A) Section of Bore; (B) the Shot. (*Mechanical Method of obtaining Rotation.*)

a hexagonal spiral bore, into which an iron or steel shot fits, and the Lancaster, with an oval bore, and a consequently oval iron shot, are good examples. The latter system can be understood by imagining a gun rifled with two grooves, and then having the angles of the grooves cut away. In both there is the objection to a possible jamming of the shot in loading; and the Lancaster gun was abandoned because of its uncertainty in this respect, as well as in the flight of its projectile, though it gave long range.

Of the second kind, Britten's (Fig. 3) and the American system in the war of 1864 are types. In each case there was a soft metal coating (*a*) at the base of the shot, which was forced up into the

grooves, by the wooden sabot (*b*), and hence produced rotation of the projectile in its passage through the bore. But the more common type of this class is that in use in England and France, where the shot, which is of slightly less diameter than the bore, has rows of soft metal (either copper, or a mixture of copper and tin) studs fixed in it, which enter the grooves, which are few in number, and so produce rotation (Fig. 4). Of the third kind, Krupp (Fig. 5) and Armstrong guns are instances. Both have an iron shot with a leaden jacket (*a*). Some of Krupp's shot are provided, instead of this, with rings of copper, but in each case the shot is larger than the bore, and will only enter the smooth unrifled powder-chamber at the breech. On the explosion of the charge the soft metal is forced into the grooves, all windage is stopped, and the shot rotated. In both guns the grooves are numerous and shallow, so that the lead coating may be easily cut through.

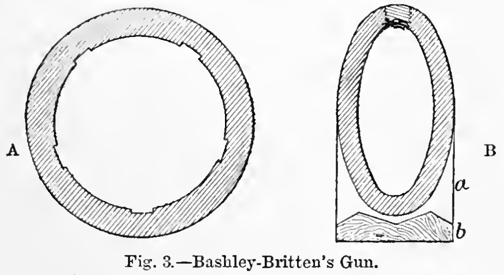


Fig. 3.—Bashley-Britten's Gun.
(*a*) Section of Bore; (B) Section of Shot; (*a*) Lead Jacket; (*b*) Wooden Sabot.
(*Expansive Method of obtaining Rotation.*)

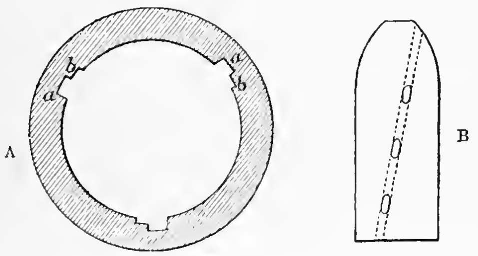


Fig. 4.—Armstrong Muzzle-Loading Shunt Gun.
(A) Section of Bore; (*a*) Loading Side of Groove; (*b*) Driving ditto; (B) the Shot.
(*Showing how Long-Shot are Centred.*)

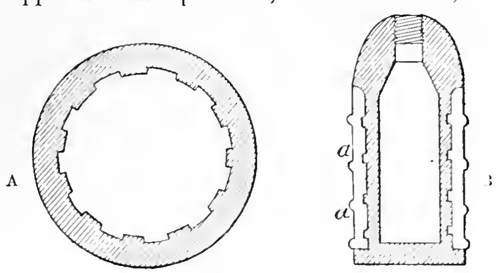


Fig. 5.—Krupp's Gun.
(A) Section of Bore; Section of Shot; (*aa*) Lead Jacket.
(*Breech-loader Method of obtaining Rotation.*)

It is beyond our province to discuss the merits and demerits of these systems. It will be sufficient to say that the muzzle loading gun is simple and strong, and the breech, being the stoutest part, admits of large powder-chambers being made, so that the loss of gas by windage is immaterial. There is also less loss of power, as the force required to press a tight-fitting breech-loading projectile through the bore (and which must be provided by the powder-gas) is considerable; so that Krupp's projectiles have less penetrative power than those of the muzzle-loading system. On the other hand, as there is no escape of gas, smaller charges can be used by breech-loading guns, and consequently more rounds per gun can be carried; while there is no scoring to the bore, and more protection is afforded to the detachments of gunners if the gun be loaded from the rear. Further, as a slow-burning powder is used in the heavier calibres, the bore has to be long, in order that all the grains may be consumed, and if to this necessary length be added that portion of the gun required to contain the breech-action, the weapon becomes unwieldy. There are advantages in both systems; and it seems quite open to question whether the breech-loading guns are not better for field service and the muzzle-loading guns for the heavier work of the navy or for fortresses.

But whatever be the system of rifling, it is not sufficient merely to twist the shot. It should be steady when it leaves the gun—that is, the axis of the shot and that of the bore should as nearly as possible coincide. At first, as the shot lies on the bottom of the bore, this is impossible, and if the grooves were quite symmetrical there would still be a tendency for the projectile to move on a small spiral round the true axis as it traversed the bore. Hence it is that the side of the groove against which the studs press in muzzle-loading systems, known as the driving side, is very often almost rectangular, while that against which the studs press, in coming out, is set at an angle, so that the studs rising up the slight incline tend to press the stud firmly against this side, and so steady or centre it. The Armstrong muzzle-loading Shunt guns (Fig. 4) are examples of the principle of centreing. The loading side (*a*) of the bore was deep, and the shot entered easily, but, on firing, the studs ran along a slightly oblique incline, and rose on to the driving side (*b*) of the groove, which was shallower, so causing the studs to fit tightly and steadying the projectile.

Any attempt to fire an elongated shot without

giving it rotation will result in its wild and uncertain flight. Plans have been proposed for making it heavier in front than in rear, with the idea that the heavy point would move first: and this is true for very short ranges. Mr. Mackay produced a gun rifled with broad, shallow grooves, and with a mechanically fitting projectile, in which it was believed that the powder-gas, aided by the friction of sawdust placed in the front of the cartridge, would cause the shot to rotate. Others, again, have suggested wings and vanes which expanded when the shot left the bore, and which were to be acted on by the air.

But all these methods were either absolute failures or very uncertain; and the certainty of the system of compelling the shot to take the rifling, by studs or otherwise, became more and more evident, and hence valuable.

Besides the form of the grooves, as influencing the steadiness of the shot, there is the nature of the twist itself. The rifling should admit of the maximum pressure of gas being given on the shot, and the minimum pressure on the bore and studs. With heavy charges and a sudden expansion of gas, the projectile may be thrust too violently forward and become uncentred, and therefore unsteady, by the sheering of the studs or by their "over-riding" the grooves. Thus it is that two spirals have been advocated: one the even, the other the gaining twist. At first the former was universally tried, and was generally too rapid, the sharpness of the turn bringing such a strain on the gun as to lead to its speedy and violent destruction, while the first pressure was always violent at the very time when the propelling force was at its highest. Later, however, though the even twist was still retained, it was made less rapid, and succeeded well. But the gaining twist simply means that the groove is at first almost straight, and then very gradually becomes more spiral; so that the shot moves easily at starting and twists more rapidly as it travels along the bore, and the gas-pressure lessens. The front studs of projectiles for these guns are therefore smaller than the rear ones, to admit of this change of motion. The object of this method is to reduce the strain upon the gun. By experiment with two ten-inch guns, each with a twist of 1 in 40 (that is, the rifling made one complete turn in a length equal to forty times the diameter of the gun) at the muzzle—the one rifled with a uniform, the other with a gaining twist—there was a maximum pressure in the former of sixty-eight tons, with a minimum of nine tons, and in the latter the maximum pressure was thirty-six tons, and very uniform throughout. The nature of the spiral therefore materially affects the pressure on the gun and studs. The powder, finally, has great influence on the shot of a rifled gun. If it burns too rapidly, the strain on the studs is great. Thus, both the size of the grain and its density have to be taken into consideration. If small, it ignites with great rapidity, burns very rapidly, and generates at once a large amount of gas. This with smooth-bored guns is no disadvantage. If large, as in the case of the pebble or pellet powder, the grains of which are as large as a hen's egg, then, though the ignition is comparatively rapid, as the flame can pass easily through the interstices between the grains, the complete combustion is slow because of the density of the grains, and the gas is generated slowly. How important this consideration is may be judged from the fact that while with "rifled large grain" powder the pressure was 29·8 tons, with pebble powder it was only 17·4 tons, the charge being 30lb. in each case. Armstrong powder, the grains of which are about as large as small peas, was rendered slightly slower in combustion by being glazed with black-lead.

It is necessary to bear these facts in mind, as the one propelling force from which the shot gets its maximum velocity, and therefore its accumulated or stored-up work, is that afforded by the powder-gas.

This maximum or "initial" velocity varies with different guns, and, of course, with different charges, but it is usually rather below 1,600 feet a second. The terms "final" or "remaining" velocity are used to express the rate at which the shot is travelling at any given point of its trajectory, and must not be confounded with the "terminal" velocity, a phrase meaning the maximum velocity which it is possible for a projectile to acquire by falling through air. The velocity at any period of the shot's flight is ascertained by means of the chronoscope, referred to in a previous article.*

So far, then, the forces which influence the flight of a projectile before it actually leaves the bore are, on the one side, the propelling force of the powder-gas, which should not act too violently; and, on the other, the friction between the shot and grooves and the resistance of the twist of the rifling. In the case of breech-loading guns, to these may be added the resistance offered by the soft metal coating to the compression necessary for the shot to take the grooves. After it leaves the gun, the propelling force necessarily begins to decrease,

* Vol. II., p. 94.

while a new set of opposing forces now come into play. These are the force of gravity and the resistance of the air to retard its direct passage to the mark; then there is the natural tendency of all rifled projectiles to deviate continually to the right (if the rifling of the gun be from left to right), and *vice versâ*. This is technically called "derivation," or "drift," and though not an actually opposing force, has to be considered in laying the gun. All these are more or less certain in their effects. Lastly, there is the effect of wind, which is, of course, uncertain. Now the spherical projectile fired from a smooth-bore gun is always more or less eccentric and irregular of surface; all such shot, therefore, owing to the fact that their centres of gravity do not coincide with the centres of the spheres, are liable to turn over in their flight, and have consequently an irregular rotation, in addition to that caused, as was before pointed out, by windage. If an elongated projectile be fired from such a weapon, this source of error is of course much increased, the pressure of the air acting unequally and irregularly on a larger surface. For example, the shot in Fig. 6, if not rotating round its longer axis *a b*, would be liable to turn over by the air-pressure

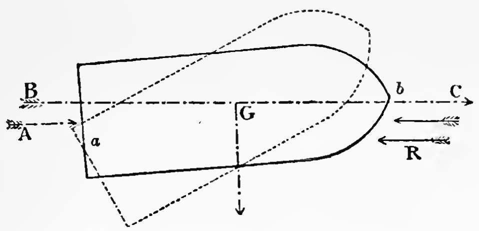


Fig. 6.—Illustrating Effect of Air Resistance on Elongated Shot. (A) Force of Projection; (B C) Trajectory; (R) Resistance of Air; (G) Centre of Gravity.

acting below the point (where, as it is falling in its curved path, the pressure is strongest) at R. But if the shot have a rotation round its longer axis, this source of error is neutralised by the air-pressure being more equally distributed; the uncertainty of rotation of all smooth-bore shot, due to their form, also disappears. The *effect* of rifling, therefore, is primarily to produce rotation round the long axis of the shot, which tends to counter balance other disturbing forces. A child's top, for instance, owes its steadiness and its resistance to the force of gravity to this very principle. The *result* of rifling is to enable us to use elongated projectiles and obtain several advantages. Weight for weight with spheres, they offer a smaller surface for resistance, and therefore range and penetrate farther; they can be made to have heads best calculated for passage through the air and penetration into the target, and as they travel point foremost, percussion fuzes can be used with certainty; they meet with less resistance than round shot, and therefore have a flatter trajectory, or path; and, lastly, all projectiles can be made of the same weight by altering their lengths, and special kinds to meet special cases can be readily employed. Of the several forces mentioned as affecting the shot's flight, that of gravity tends merely to drag the projectile downwards; and if the retarding action of the air be for a moment disregarded, it is capable of proof that the result of this force, and that of propulsion received from the powder, would be to make the "trajectory," or curved path of the shot through the air, parabolic. But the resistance of the air materially modifies the form of the trajectory, and the amount of resistance depends, first of all, on the shape of the shot itself. This retardation is influenced by the form of the rear end as well as the fore end of the projectile, and must not be confused with the best form for penetrating a hard material, such as iron. For example, some of Whitworth's bolts are flat-headed, with the object of acting as a punch would do: yet this form is not a good one for diminishing the effect of the air's resistance. Three forms have been generally employed: the conical, or vertical section of a cone; the conoidal, a figure formed by the revolution of a conic section round its axis; and the ogival or pointed arch shape. Of all three the ogival seems by experiment to experience the least resistance; but the shot proposed by Whitworth was conoidal in front and tapered behind, and this gave the best results as regards range. But though this form was possible with a shot having such long bearings as his, it could scarcely be adopted in the studded projectiles of guns rifled with few grooves, because of the unequal strain that would be brought upon the studs themselves, and render them liable to sheer. The velocity of rotation, being the means whereby the effect of the opposing force is modified, must of necessity vary with the character of the projectile used and the velocity of propulsion. For as the initial velocity of the shot increases, so will the resistance of the air, tending to upset it, increase, greater length giving greater leverage on which the air can act; while the form of the head, giving a greater or lesser surface on which it can press, also increases the effect of the disturbing force, and necessitates a more rapid spin. Thus long projectiles, which have a natural tendency to droop, and flat-headed ones, such as Whitworth's bolts,

when the air directly opposes the head instead of operating obliquely on it, require a more rapid rotation, and therefore a quicker twist in the spiral of the rifling. A good length for a shot is about two calibres, or twice the diameter of the bore. Even the density of the mass influences this question. Hollow shells are steadier than solid shot of equal weight, for "the mass being distributed farther from the axis, the radius of gyration is lessened." If, again, the centre of gravity of the shot be very far back, the base has a tendency to droop, and high velocity of rotation is required to keep it steady. Thus the nature of the gun, as far as its system of rifling goes, and the character of the shot, act and re-act the one on the other. And not only are the theoretical opinions advanced found generally true in practice, but the effect of air-pressure can be proved by the gyroscope. The disc employed in ordinary experiments is replaced by a small elongated shot, furnished at its base with a projecting piece of metal wherewith to give it the necessary spin. It is held in two rings, so arranged that one can turn on a vertical, the other on a horizontal, axis: so that its movement is free in any direction. When made to rotate, a current of air is directed, by means of a blower, on any part of the shot, which may be of any required form, and the effect of air-pressure very clearly demonstrated. Though the shot has no "motion of translation," the effect of causing the air to impinge on it produces the same result as if it impinged on the air.

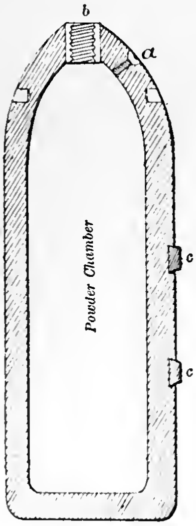


Fig. 7.
Section of Common Shell.

The "derivation," or "drift," of elongated projectiles before referred to is also influenced by the form of their heads. Thus, with conical-headed shot the deviation is always to the right when the rotation is right-handed, but owing to air-pressure, the reverse is the case if the head be flat.

It remains, lastly, to examine the work the shot will do. This depends on what it is required to do. In the case of shells that are intended to burst without penetrating an object, the form of the head would be such as would render passage through the air easy, and of the body such that it would contain the proper charge of powder or bullets. With shells or shot designed to penetrate the object aimed at, the form of the head is of greatest importance. There are three general classes of projectiles used in war. Common shells for incendiary purposes, or for the penetration and shattering of materials other than iron plates. Thus for bombardment against wooden or thinly-plated vessels, or against earthworks, when the bursting-charge would act like a small mine, this kind of projectile is employed. Fig. 7 represents the section of a common shell: *b* is the fuze-hole, in which the fuze, which may burst on striking (percussion fuze) or after a certain lapse of time (time fuze), is inserted; *a* the unloading-hole, in case, after the fuse is entered, and when it might be dangerous to remove it, the bursting-charge may have to be removed; *c* the studs by which rotation is effected, and which are "swedged" into under-cut holes made for the purpose. Their destructive effect may be imagined when it is remembered that for the 12-inch gun the shell is about 30 inches long and contains 35 lb. of powder.

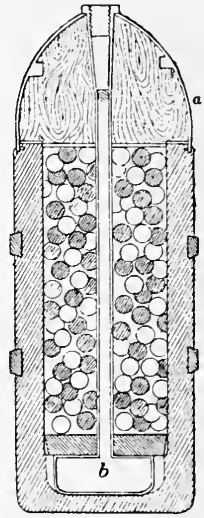


Fig. 8.—Section of Shrapnell Shell.

Next, there is the Shrapnell shell for firing against troops; its destructive effect being chiefly due to the hardened bullets, of variable size, with which it is filled. With the common shell, the violence of explosion is most important; but with this, the bursting-charge (*b*) is only sufficient to open the iron casing without disturbing the velocity of the bullets, which has been acquired by the velocity of the missile itself. In Fig. 8 it will be seen that the head is of wood, cased in iron *a*, which is merely added to give a suitable form for the passage of the cylindrical box of bullets through the air. The central channel is the means of communication between the fuze and the small bursting-charge; and one element of value this shell especially possesses is that it is excellent with time fuzes, and it is therefore available when, owing to the soft nature of the ground, percussion fuzes could not be employed. The number of bullets, of course, varies, but the 9-inch Shrapnell contains 564 12-ounce balls. "Case" shot is also used against the *personnel*, but only at short ranges, and is unprovided with a bursting-charge, the force of the

powder-gas being sufficient for breaking up the case containing the bullets.

Against armour-plates, or for battering purposes, the Palliser shot or shell is alone used. In external shape they are similar, and the only internal difference is that the central hollow is larger in the latter than in the former. They are made of cast-iron, the head being chilled. The reason for this is simple. For penetrative purposes a shot should have as hard a point as possible, and yet, for economical reasons, be cheap in manufacture. Steel is too expensive a material under these circumstances; but it was well known that iron cast in a metal mould cooled rapidly and acquired an intense hardness, but, at the same time, excessive brittleness. In this state it is known as white iron, to distinguish it from ordinary cast-iron, in which the carbon, in the form of graphite, is mechanically diffused through the mass, giving it a grey or mottled appearance. This always occurs when iron is slowly cooled.

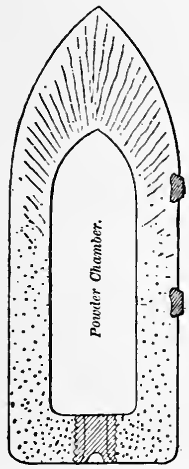


Fig. 9.—Section of Palliser Shell.

To chill the entire shot, and make it all hard and brittle, would lead to its base being possibly fractured by the shock of the powder-gas; so that Palliser projectiles are cast with the head in an iron, and the base in a sand mould, thus producing an intensely hard-pointed, but otherwise comparatively soft shell.

But the most important thing to notice in the Palliser shell is the form of the head. This is "ogival," struck with a radius of from one and a quarter to one and a half; so that the shock of impact may be converted into a gradually increasing pressure. Fig. 9 shows a section of one of these, the lines in the head indicating the radiating lines of sudden crystallisation, and the dots in the rear part the mottling of the iron, due to the presence of the graphite spots. No fuze is necessary; for the heat generated by impact, or perhaps the sudden percussion of the powder charge on the front of the shell when it strikes, is sufficient to ignite it.

The work the shot will actually do depends on the stored-up work in it, due to the velocity imparted to it by the powder-gas, modified by its weight, form, and diameter. Some portion of this work will be expended in breaking up the projectile itself; and it is found, in practice, that while the head of a Palliser shell after destructive impact is comparatively cool, the fragments of iron of the broken base, as well as those of the iron plate penetrated, are extremely hot. That is to say, the work of which the head was capable was fully expended on the plate, but that portion of the work that was expended in breaking the shot or shell was developed in the form of heat. With a badly-formed shot the head would be, and is, hot like the other fragments. The penetration should be "directly proportional to the work in the shot, and inversely proportional to the diameter of the projectile." Elongated projectiles penetrate farther than balls of equal weight, because, while having a less area to oppose to the resistance of the object, owing to their form, they will, being less retarded during their flight, have a greater final velocity; but, at the same time, the initial or starting velocity of the smooth-bore is generally greater. Shape of head is of paramount importance in penetration. Blunt-headed forms, especially if the material be wrought-iron, not only "set up" on impact—that is, bulge at the head—but even if perfectly flat, like a punch, they cut out a portion of an armour-plate, which piece they carry in front of them, adding to the work to be done. Ogival-headed shot, more particularly if chilled, do not "set up," and, penetrating more readily, thrust aside, as it were, the fibres of the opposing metal in their passage through it.

It is not considered sufficient now, as it was when iron-plated ships were first introduced, to attempt the destruction of the armour by firing heavy spherical projectiles with low velocities, as did the Americans in 1864. As the method of construction of the cuirass improved, it became more and more evident that "racking," as this was called, was far inferior to "punching" in its effects, and shot having high velocities and of good penetrative shape came into general use.

The amount of work that a punching or penetrating projectile can execute on any iron target is estimated by calculating, first of all, the *stored-up work*, or *energy*, in the shot at the moment of impact. This is arrived at by the formula—

$$\text{Work} = \frac{W.V.^2}{2g \times 2240},$$

where W. is the weight of the shot in pounds, V. its velocity in feet per second on striking, g the force of gravity (32·2), and 2240 the number of pounds in a ton. If, however, it be required to

ascertain approximately the penetration of a projectile into iron plates, the formula

$$\frac{W.V.^2}{2g \times 2240} = 2\pi r \times b^n \times K$$

must be employed. Here $\pi = 3{\cdot}14159$, $2r =$ the diameter of the shot in inches, $b =$ the thickness of the plate to be pierced, $n =$ a constant quantity dependent on the quality of the plate (usually taken as 1·6 for wrought-iron), and $K = 2{\cdot}53$ a co-efficient, depending on the nature of the wrought-iron in the plate and the form of the head of the shot. For example, a 9-inch Palliser shell, having a final velocity (that is, at the moment of impact) of 1,304 feet, would have

$$\text{Total energy} = \frac{250 \times (1304)^2}{2 \times 32{\cdot}2 \times 2240}$$
$$= 2946{\cdot}9 \text{ foot tons};$$

and dividing this by the circumference of the shot in inches, we find that the energy per inch of circumference is 105·16 tons. Again, supposing it were required to find the thickness of the plate penetrable by a 38-ton gun, the final velocity of whose projectile was 1420 feet per second, we should have

$$b^{1.6} = \frac{812 \times (1420)^2}{2 \times 32{\cdot}2 \times 2240 \times 3{\cdot}14159 \times 12{\cdot}5 \times 2{\cdot}53};$$

or $b = 19{\cdot}33$.

In practice against a target with an iron plate 19·5 inches thick, it was found that the shot had penetrated, "leaving its base in the hole," thus proving the correctness of the formula.

Thus it appears that the work a shot is capable of doing depends, first of all, on the character of the rifling and the amount of the powder charge, both of which affect the velocity; next, on the form given to it and its rapidity of rotation, whereby the action of the air's resistance is modified; and lastly, on the material of which it is composed, the form given to the head, and the nature of its contents.

WHY THE RAIN FALLS.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

Amongst the several notable properties which fit water for the important part it plays in the material arrangements of the habitable earth, its fluidity, or power of flowing, stands conspicuously out, both on the ground of usefulness and interest. This attribute of ready and fluent movement under the slightest extraneous impulse is not, it is true, an exclusive privilege of aqueous existence, for it is shared by all the material substances which are what is termed of a liquid consistency. But water,* of such substances, alone is found in great abundance in a natural state, and is, indeed, so universal and constant in its presence that it assumes the place of Nature's own favourite representative of this liquid phase of material existence. As rivers, water runs down all the sloping channels sculptured out upon the terrestrial surface between the hills and the sea; and as the ocean, it flows round the earth, and fills all the deepest depressions that are hollowed into the ground.

The great physical peculiarity which confers this power of fluent movement upon water is, that the myriad of little particles of which its substance is composed, although lying near together, are, nevertheless, perfectly free to glide over each other, and roll independently about. They have no inclination or tendency to get far apart, and they have no inclination or tendency to hold firmly together. In the case of a solid substance, such as a lump of stone, the constituent particles cling to each other with such a resolute grip that it takes the blow of a heavy hammer to force them asunder; and even then, when they have been subjected to this violent interference, they only part company in a few places through the mass, so that it is broken by the stroke into a limited number of fragments, instead of being loosened throughout into its ultimate molecules. In water, and in all liquid substances, the primary, or ultimate molecules, on the other hand, all lie side by side without being bound to each other by any kind of cohesive grasp, so that the slightest impulse causes them to shift their places amongst each other.

When water is frozen into ice, it acquires the same kind of solid hardness as a stone. Its constituent particles are then bound by the influence of the cold so firmly to each other that a lump of the ice can be carried about in the hand, just as a stone might be, without losing its form. If the lump be laid upon the ground, the ice-particles which are at the top of the mass are sustained

* See "Science for All," Vol. I., p. 208; and Vol. II., pp. 25, 62.

there by their firm adhesion to the particles beneath; but if, in such circumstances, the ice is suddenly melted by heat, the adhesion between the contiguous particles is destroyed, so that the weight of those which are above makes them slide down over the lower ones until they reach the ground, and then continue to roll along the ground, if its downward slope affords the facility for doing so, just as balls roll down the face of a hill. The flowing down of water is entirely due to the attraction which the earth exercises upon the little molecules. So soon as there is no opposing force adequate to the prevention of the result, the molecules roll down under the pull of the attraction, gliding and sliding over each other as they do so. The molecules which glide and roll over each other in this way are, it will be understood, exceedingly minute bodies. It will be remembered what has been already said in a preceding page * of the minuteness of air-atoms. The statements there made in reference to the dimensions of those bodies apply with very nearly equal force to the individual molecules of water. Each separate molecule of the liquid is certainly not more than three times the size of the elementary atom of air. Each molecule of the water in reality consists of just three such primary gas-atoms, associated together as a group. In each molecule of the water there are—as we have already seen †—one atom of oxygen and two atoms of hydrogen, both gaseous elements, agglutinated together by the agency of an aggregating force. The union of the three gaseous atoms into a molecular group does not, however, affect the question of dimensions in any very material way. The little mass built up, or molecule, is still much too small to be seen when it is separated from all its companion molecules. Water in bulk is visible only because many molecules are drawn very near together, and so appear to the eye as a connected mass. The separate particles or individual molecules which are clustered together in water can no more be seen, even by the help of the most powerful microscopes, than the ultimate atoms of air.

That the individual molecules of water are thus absolutely invisible to the eye on account of their minuteness, when they are floated widely asunder, can be easily proved. When a very cold drinking-glass, which has been wiped perfectly dry, is brought suddenly into warm air that is itself transparent and invisible, the glass becomes dimmed all over its outside with trickling moisture. All this moisture is drawn out of the invisible and transparent air. It was present in it when in the clear and transparent state, and it was invisible then because its constituent molecules were floated widely apart in the spaces intervening between the air-atoms. It becomes visible upon the glass only when a considerable number of the widely-spread molecules are drawn together by the influence of the cold.

The floating-up of the minute and altogether invisible water-molecules in this widely-severed state into the air, however, introduces some further considerations in reference to molecular existence, which require to be dealt with here, on account of the bearing that they have upon the production of rain. In the first place, the constituent molecules of water, when they lie in close contiguity in the liquid state, and glide about over each other, do not actually touch. There is at all times an absolute, although a very narrow, chasm or interval between molecule and molecule. They float at a definite and quite appreciable distance apart, being held at that relative distance by the influence of opposing and carefully balanced forces. The weight of the molecules, or, in other words, the attraction exerted over them by the earth's mass, draws them into close contiguity to each other; but when they have got into tolerably close neighbourhood, a new force comes into play, and resolutely prevents them from getting into absolute contact, and they then remain at this distance, poised between the antagonistic and oppositely acting impulses—hung up, as it were, between the pull and the push.

It is perhaps hardly possible to give, in the existing state of physical science, a complete and quite satisfactory explanation of the nature of this repulsive force which acts between the contiguous molecules of material substances, and which keeps them from coming into actual contact, even when pressed powerfully together. But it can at any rate be made obvious and plain that it is an immediate and unavoidable effect of the operation of the power, or state, which is familiarly known as "heat." With each fresh accession of heat, the molecules of any heated substance are held further asunder. When some definite quantity of water is heated by the action of sunshine, or of an artificial fire, the molecules of the liquid mass repel each other with augmented force, and move a little farther apart, although still drawn together by an approximating energy that has undergone no change. The water then consequently occupies an actually larger space. A pint of hot water has a larger bulk than the same weight of water when it is cold. If the water, on the other hand, be chilled, instead of being

* Vol. I., p. 322. † Vol. II., p. 62.

heated, the inter-molecular repulsion grows less, and the molecules approach a little more nearly together. The attraction then so far preponderates over the repulsion.

The scientific notion, at the present time, regarding heat is simply that it is a state of unceasing movement or play of the molecules of material substance. There is no certain knowledge as to what the exact character of this intrinsic molecular commotion of a heated substance is. Some authorities are satisfied to conceive that the molecules are in a state of unceasing whirl, revolving upon themselves as spinning-tops revolve upon their axes, and that this whirl is urged on ever faster and faster as the heat mounts up to a higher intensity. Other authorities, again, assume that the movement is more of the nature of a vibratory swing—a to-and-fro play. Possibly there may be a combination of both these modes of molecular disturbance. The vibratory play may itself, indeed, be in some sense a consequence of the rotary whirl. At any rate, the conception of a vibratile swing of the molecules very naturally accounts for increase of dimension with augmented heat. When the molecules make more energetic excursions from side to side, it is obviously indispensable that they must have more space occupied by their to-and-fro swingings.

There is one consequence, however, of this vibratile commotion of the molecules which is of great practical moment in the case of water, on account of the serviceable results which ensue. The vibratory or to-and-fro play of the molecules is checked within certain definite limits, or controlled, in the main bulk of the liquid, on account of the resistance which the swaying particles meet when they approach towards impinging upon each other. But at the upper layer of the liquid mass, where it comes into immediate connection with the air, this does not occur to the same degree. The swaying of the molecules is only resisted when they are pressed downwards into the subjacent liquid mass. When they rise upwards towards the thinner air, large numbers of them are tossed off, and bound freely away into the open spaces that lie between the widely-spread atoms; and in those inter-spaces they float well apart, like the air-atoms themselves. The aqueous substance, indeed, literally becomes changed into the state of air; although in this particular case the air-like condition is characterised by a distinct name, and called "vapour." Vapour is merely the loosened-out and widely-spread condition in which the molecules of water are found when they are scattered asunder from each other, either in otherwise void space, or in the intervals that exist between gaseous particles. The aqueous molecules which have been alluded to as existing in an altogether invisible state in warm air, until they are brought together by the chilling or condensing influence of a cold glass, are precisely in this state. They have been originally tossed off into the air from the upper surface of some collection of liquid set vibrating and pulsating by the agency of heat. The passing off of the molecules of water in this way from the upper surface of any collection of liquid, into the thin and, so to speak, dismembered state of widely-spread gas, is the process which is technically known as "evaporation." Evaporation is essentially the transformation of liquid water into gas-like vapour.

The quantity of disembodied vapour which is thus tossed off from the upper surface of heat-disturbed water in any given interval of time depends, however, essentially upon the degree of heat which is present in the liquid. The greater the heat of its mass, the more energetic is the vibratory play of the aqueous molecules, as has been already said; and the more energetic this vibratory play, the more abundant is the stream of the molecules which are tossed up into the air, or into free space. When the heat is raised as high as the state which is known as the boiling-point of water, or 212° of Fahrenheit's scale, the vapour even bursts in great globular masses from the very depths of the liquid, as well as from its upper layer, where it is freed from the superincumbent pressure of the liquid mass, and is in presence only of the lighter and thinner air. It is the bursting out of the suddenly generated vapour through the general bulk of the liquid, which constitutes the familiar state of bubbling or "boiling." *

It is now pretty generally accepted by scientific men, as in the highest degree probable that the molecules or ultimate atoms of material substance, when they are once scattered freely asunder into the condition which prevails in gaseous and vaporous bodies, retain the heat-generated and energetic movement which has been impressed upon them, and dash widely about in bold excursions, instead of moving to and fro in almost infinitesimal tremblings, as they do whilst bound down by the exigencies of a liquid or solid mass. It is conceived that each atom or molecule rushes forward in an onward path until it strikes against some other

* A word apparently derived from the Icelandic word *bulla*, "to bubble up."

molecule, or some coherent mass, and that it is then thrown back into a retrograde course, just as a billiard-ball is when it strikes full upon another ball, or upon the elastic cushion of the table; and that the rapidity and force of these molecular flights is greater in proportion to the heat which is present amongst the molecules. When a gas, or vapour, is contained in a closed vessel, such as a jar of glass, it is well known that it presses outwards against the sides of the vessel, and that it does this with a force which increases with augmentation of heat. According to the modern doctrine of the molecular movement of gases, the pressure which is exerted upon the interior surfaces of the containing vessel is due to the actual blows or impacts of the molecules dashing themselves unceasingly against their prison walls. The theoretical reasonings about this ingenious conception have, indeed, been followed up so far that calculations have been made as to the speed with which the molecules of certain gases move as they fly to and fro at given temperatures. It must, however, on no account be overlooked, in reference to this mode of regarding the matter, that the movements of the molecules cannot be really seen, or, indeed, be in any way detected by the direct agency of any sense. They affect bodies which are withdrawn quite beyond the sphere of sensual perceptions, and are therefore phenomena that are reasoned out, rather than observed. They are conceived as conditions which are probable in a very high degree on account of the intelligible and satisfactory explanations which their assumed existence gives of effects that are appreciable to the senses, and that can be made the object of examination and experiment. It may be fairly held that they are, at any rate, approximations to the real facts of the case; and that the molecules of matter do behave somewhat in the way which is described, although very possibly it is only half the truth which has been yet seized by human intelligence in regard to them; and the day may be yet looked for when some new light will be shed upon these as yet only partially revealed mysteries of the physical constitution of nature.

It has been said that vapour rises up from the surface of water into the air in consequence of the shooting forth of the separated water-molecules under vibratory action, which unceasingly goes on, and that it rises up more abundantly, and more rapidly as it is more energetically acted upon by the disturbing power of heat. This broad statement, however, it must be understood, is limited and qualified in one important particular. The outpouring of the molecules of the vapour can only go on until a certain definite load of the water-molecules has been accumulated in the air; and the load which can be in the end sustained without further accessions of vapour, is greater or less accordingly as higher or lower degrees of temperature are operative at the time. Thus at the temperature of freezing water the interspaces of the air can receive the one-hundred-and-sixtieth part of the atmosphere's own weight of aqueous vapour, and when they have taken up so much, they cannot receive any more; the load of the vapour then rests upon the water-surface with a controlling pressure which prevents any more of the vibrating particles from being shot off. At the temperature of 59° the air can receive the eightieth part of its own weight of vapour; and at 86° it can receive the fortieth part of its own weight. For each fresh addition of 27° of temperature, the capacity of the air to receive and sustain aqueous vapour is doubled. When the air contains as much watery vapour between its particles as it can receive without manifesting its presence as visible mist, it is said to be in a "saturated" or satiated state. The saturation of air with moisture means that it has as much watery vapour, in a transparent and invisible state, mingled in amidst its own particles, as it can hold without throwing it down as visible water.

It is, however, yet again, a curious, and hardly to be anticipated fact, that in the entire absence of air, just the same quantity of aqueous vapour can be sustained at any given temperature, in a transparent state above the surface of the liquid, as would rise in the presence of the air. The familiar expression, so constantly used, that so much moisture is sustained by the air, is hardly to be reconciled with the actual reality of the case. The naked truth is that the vapour is sustained altogether irrespective of the influence of the air. It is supported by the agency of heat, and is upheld in precisely the same way, both in the presence of air, and in vacuous space. The full saturation of the space is, indeed, brought about more quickly in the absence than in the presence of air. The real influence of the air-atoms is that they retard to some extent the penetration of the aqueous molecules amongst them; the vapour is impeded in its onward flow by the air-particles that cross its path. But, just for the same reason, when air is drifting along in the condition of wind, it carries the floating vapour associated with it, and entangled amidst its particles. The vapour and the air are primarily subjected to an altogether distinct

physical control; but there is nevertheless some sympathetic bond, which has hardly yet been sufficiently investigated and defined, connecting them together.

It is for this reason that increased pressure of air retards, and in the end lessens, the evaporation of water. In the face of the great law that vapour rises from water in the same way whether there be air or vacuous space above it, this ought hardly to be. The explanation of this seeming contradiction properly is, that the molecular condition of the surface of the water is so far changed by the augmented, or diminished, pressure of air, that in the one case the vibration and throwing off of the molecules is more checked, or damped, than it is in the other. The weight of the air diminishes the supply of vapour by pressing upon the water, although it is quite incapable of exerting any similar controlling pressure upon the vapour-molecules, when these have once been disentangled from the actual surface of the liquid. It damps and embarrasses the vibratile play of the molecules of the uppermost film of the liquid, although it does not in any way press upon the molecules of the already risen vapour.

Under the several physical conditions and relations which have here been described, vapour is thrown up from the broad ocean, and from the moist porous surfaces of the earth, until the interspaces that lie between the particles of the superjacent air are copiously charged. The vapour-molecules then get so far entangled amidst the atoms of the air, that they are drifted along with them in whatever direction they may themselves be advancing, under the impulse of the wind. This, therefore, is properly the first stage in what, by a loose but convenient and expressive figure of speech, may be termed the manufacture of rain. In favourable circumstances, such as exist in the broad ocean-spaces of the torrid zone of the earth, the drifting air soon drinks in the abundant charge of vapour which, at its warm temperature, it can contain. The copious load thus acquired is then wafted away to cooler regions of the earth, where, in the first instance, the saturation becomes complete because the temperature of the air gets lowered to the requisite degree. With any further chill beyond this, the superfluous vapour that cannot be retained at that lower temperature is gathered first into visible mist, or water-dust, as it has been happily termed, and then into round globules, or drops, which are too heavy to be any longer sustained by the flotation powers of the moving wind, and consequently fall to the earth in continuous showers. The rain-making process is then complete. Whenever warm vapour-laden air arrives in positions of the earth where it gets rapidly chilled, rain falls as a matter of course, as a simple result of the arrangement which renders cold air unable to sustain the same charge of floating vapour which warm air can support.

At a temperature of 32° Fahr.—the freezing-point of water—air can sustain 2·37 grains of aqueous vapour in each cubic foot. If in such air at any time there were 2·38 grains to the cubic foot, the superfluous hundredth of a grain would, of necessity, appear in the form of condensing mist. At a temperature of 60°, each cubic foot of fully saturated air would contain 5·87 grains of invisible vapour; and at a temperature of 80° each cubic foot would hold 10·81 grains. If, consequently, at any time fully-saturated air at a temperature of 80° were suddenly chilled down to 60°, nearly five grains of water-drops, or rain, would of necessity be poured down out of each cubic foot of aërial substance. It does not at all matter how such chilling effect is produced. It may be by the rapid admixture of distinct currents of air, the one warm and the other cold. Thus, if, in the conflict of antagonistic winds, a cubic foot of air with a temperature of 80° were mingled with a cubic foot of air with a temperature of 40°, there would be two cubic feet of air, or thereabouts, with a temperature of 60° throughout. Or, on the other hand, the chilling of the air may be the result of the bodily movements of the warm air to a less heated part of the earth; or to the sliding of the warm air-mass up along the slopes of lofty hills. When this latter occurrence takes place, as it invariably does where an ocean wind drives in against the shores of a mountainous or elevated land, the air first gets expanded as it rises into the higher regions, where the pressure of the superincumbent atmosphere is less, and then becomes cold as a consequence of the expansion. Whenever air is expanded into larger dimensions and thinner substance, sensible heat is taken up, and as it were consumed for the time, to be turned to account in keeping the air-molecules farther apart, instead of in warming the mass. Rain is effectually produced, then, by any of these causes of chill. It occurs when a moist warm wind blows in from the ocean upon cold stretches of land. It occurs when dense, vapour-laden winds are pressed up the slopes of abruptly-rising hills, and it takes place whenever warm ocean winds are mingled with

cold blasts in the surgings of the tempestuous conflicts of the atmosphere. Even cold, dry winds may be the immediate cause of rain, if they blow suddenly in upon a mass of warm, vapcur-saturated air.

The difference between the physical state of a gas which is not condensible into a liquid at ordinary temperatures and pressures encountered naturally upon the earth, and that of the vapour which is changed into the liquid state under slight variations of natural temperatures and pressures, is very admirably illustrated in the case of air, and of the aqueous vapour which is mingled with the atmosphere. The gaseous air, it will be remembered, has no liquid reservoir; it is a fixed and approximately unchanging gaseous investment of the earth. The main bulk of the water, on the other hand, lies in a liquid state in the wide and deep basins of the sea, and only a small and quite subordinate part of it is scattered around its outer surface as expanded vapour. There are various considerations of great practical interest which arise out of this difference. But the allusion to these must unavoidably be left for other opportunity. The one pregnant circumstance which is here for the present occasion selected from amongst them, and held up apart to be seized by the attention and memory, is the leading feature and fact that the quantity of vapour which can be raised out of the great reserve basin of the sea is determined and fixed by the quantity of heat which is available for the purpose at any place, and that such quantity varies to a very large extent even within the limited range to which natural temperatures extend. With the largest amount of heat which is furnished by the sunshine that falls on the earth, a copious abundance of the vibrating molecules are shot off from the surface of the liquid seas to assume the expanded state of scattered vapour. But, under privation of sunshine, a good part of those molecules are gathered back from the scattered vaporous state until they cohere into water-drops, and fall back to the ground or sea. Cold, when applied to the invisible floating vapour, diminishes the energy of the impulse or swing by which the aqueous molecules are kept floating apart, and so enables them to be drawn back into liquid water.

As a general rule, vapour is raised in the most copious abundance over the equatorial and intertropical seas, and is transported to the temperate and colder regions of the earth, and especially to the more elevated lands lying in those regions, to be deposited. But this general rule is modified in a very remarkable and, indeed, surprising degree, by the influences which have been described in a preceding page* as ruling the local distributions and variations of temperature. The consequence is that rain is poured fitfully and intermittently over the land-spaces of the earth. The rose of Nature's own watering-pot, so to speak, is swept bounteously over the ground, now in this direction, and now in that, so that all parts of the earth receive a due share of the fertilising showers, as well as of the quickening sunshine that alternates with the clouds and rain. Since the capacity of the air to sustain aqueous vapour depends upon heat, and since this heat is in a condition of never-ceasing change at all places, such must be the result in the matter of the rainfall. The varying temperature and the varying winds efficiently insure the watering of the earth everywhere excepting in the few happily limited desert tracts which are as destitute of living creatures as they are of rain.

One further consequence of this method of ordering the rainfall is that there is a very great difference in the quantity which is deposited on different parts of the earth. Most rain falls where hilly or elevated coasts are exposed to the inflow of warm ocean winds, and least where prevalent winds drift in from cold, dry regions to low-lying, sunny lands. But over and above this there are circumstances connected with the sculpturing and exposure of the land, which make the difference very great within very narrow limits of territory. Thus in Cumberland there are places within two miles of each other at one of which the average annual rainfall is 47 inches more than it is at the other. The annual fall at any one place also differs materially in different years, accordingly as warm and moist, or as cold and dry winds have been predominant. On account of the great diversity which attains in the amount of rain deposited on different parts of the earth, it becomes very difficult to ascertain what the sum total over the whole earth must be. If the amount of water that is thrown up into the air from seas, rivers, moist ground, and living vegetation could be measured, that of course would give a fair estimate of the rainfall of the earth, because it may be safely assumed that all the water which is raised into the air as vapour is ultimately thrown down again to the ground as rain. Commodore Maury, the distinguished meteorologist of the United States, calculated that about 16 feet of

* Vol. II., p. 123.

water, assumed to be of the same area as the surface of the earth, is evaporated into the air within a year. More recent authorities consider, however, that this estimate must be largely in excess of the truth, and that if all the rain which falls upon the earth were allowed to accumulate in a basin of the same area as the terrestrial surface, it would amount to a collection 8 feet deep at the end of a year. The average rainfall of the British Islands appears to be something like 36 inches in the year; and the average rainfall of London is certainly about 25 inches, or a little more than 2 feet in the year. The annual rainfall in the driest parts of the British Islands amounts to about 18 inches, and in the wettest parts, amongst the mountains of Cumberland, it amounts to 189 inches in the year. The heaviest rainfall known upon the earth occurs upon the mountain slopes beyond the head of the Bay of Bengal, and amounts upon the average to 610 inches, or nearly 51 feet, in the year. One inch of rain implies a fall of 101 tons of water upon each acre of ground. The average rainfall of London therefore entails a supply of 2,525 tons of water in the year to each acre of ground, or 31,310,000 tons for the entire metropolis, estimating it at an area of 20 square miles.

The rainfall at any place is ascertained by catching the amount of water which falls in an instrument which has been contrived for the purpose, and which is known as the rain-gauge. If a cylindrical vessel, with a circular mouth having exactly the same diameter as the interior of the vessel, were used to catch the rain, the depth of the accumulated water, measured in inches and decimal parts of an inch, would express the quantity which had fallen through that mouth in any fixed interval intervening between two regular periods of observation, such as twenty-four hours. This, however, implies that some contrivance is employed to prevent any portion of the water that has been collected from escaping in the meantime by evaporation. But when the rainfall between successive observations is small—such, for instance, as a hundredth part of an inch for the horizontal area of the gauge, it is obviously difficult to measure it exactly in this direct way. On this account the expedient is adopted of catching the water, as it falls, in a funnel, so placed as to carry it into a smaller interior vessel. The principle involved in this method of measuring is illustrated in the accompanying sketch (Fig. 1).

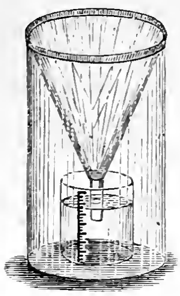


Fig. 1.—Showing the Principle upon which small Quantities of Rainfall are measured by Rain-Gauges.

If it be assumed that in this figure the mouth of the receiving-funnel has four times the area of the jar contained in the interior of the cylinder, then a depth of four inches of rain collected in the jar would indicate a fall one inch in depth for the area of the mouth of the funnel. In rain-gauges commonly in use, the measurement is made still more exact by catching the rain in some interior vessel, and then pouring it out into a long and narrow glass jar, which is graduated into hundredths and half-hundredths of an inch, such as is represented in Fig. 2, the graduations being duly adjusted to the area of the funnel. The evaporation of the water between the periods of observation is prevented by having the funnel of the gauge contrived as shown in Fig. 3. The funnel F lifts off from the top of the lower part of the receiving cylinder C, and discharges itself at the bottom, when in use, into that cylinder by a small pipe P, turned up so as always to retain two or three drops of water in the bend. The dotted lines P *a*, P *b*, show how the sides of the funnel are inclined to lead down to the curved pipe which discharges into the cylinder. The water collected in C is poured out into a glass measure like that which is represented at Fig. 2, whenever its quantity has to be estimated.

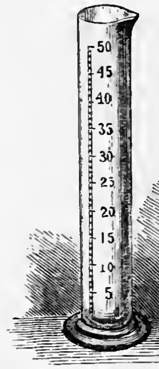


Fig. 2.—Showing graduated Measure, used to estimate small Quantities of Rainfall.

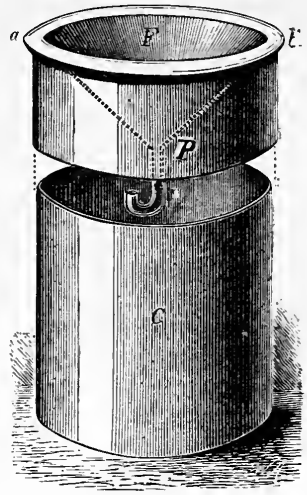


Fig. 3.—Showing the Arrangement employed in Rain-Gauges to prevent the Loss of Water by Evaporation.

A very convenient and cheap form of rain-gauge may be provided by having a small circular copper funnel, something like that which is shown in Fig. 4, prepared with the mouth carefully turned so that it measures 4·697 inches across within its

rim. Such a funnel then has an area of 17·33 square inches; and as one fluid ounce of water measures 1·733 cubic inches, a fluid ounce of water collected from rain falling into the funnel represents exactly a tenth part of an inch for a cylindrical vessel as wide as the top of the funnel. The great advantage of this form of instrument is that no other measure is required for estimating the fall in tenths of an inch than the ordinary fluid ounce measure of the apothecary, which can always be procured anywhere. Each ounce of water thus measured indicates one-tenth of an inch rainfall. The ounce can be further sub-divided into tenths—which then represent hundredths of an inch—by any simple expedient, such as marking the sides of a carefully moulded ounce phial into ten equal parts. If at any time the graduated measure is broken by accident, another, equally reliable, can be immediately procured. The funnel is generally placed in the mouth of a glass bottle to collect the rain, and if its sides fit fairly well to the mouth, no evaporation of any consequence takes place.

Fig. 4.—Representing a convenient Form of Rain-Gauge, to be used with a common Fluid Ounce graduated Measure.

The amount of free moisture present in an invisible state in the air is estimated by instruments which are termed hygrometers. The one invented by Professor Daniel, which is a very convenient form to use, is shown in Fig. 5. A bent glass tube is terminated at each end by a bulb somewhat exceeding an inch in diameter; one side of the tube A, which is the longer one, has a small thermometer inclosed within it, and some sulphuric ether at the bottom of the bulb, surrounding the ball of the thermometer; and there is also an outside thermometer fixed to the central stem of the instrument.

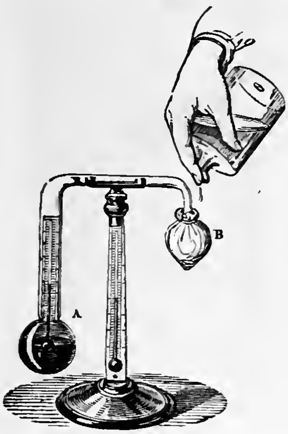


Fig. 5.—Daniel's Hygrometer, for measuring the Moisture of the Air through the Effect of the Evaporation of Ether.

The bulb B at the shorter end of the tube is covered by a coat of muslin, so that ether can be poured upon it at will from a phial, as represented in the figure. When ether is so poured upon the muslin, it makes the covered bulb of the tube very cold by rapid evaporation. Vapour of ether in the inside of the tube, which has risen into it from the bulb A, is on that account condensed, and further evaporation of ether then goes on from the bulb A, containing the thermometer inside, and cools it down, until at last dew begins to deposit upon the outside of the glass. At that instant the readings of the two thermometers, one inside and one outside, are compared; and from the difference of these readings the quantity of aqueous vapour in each cubic foot of air can be ascertained, by reference to tables which give what is termed "the tension of aqueous vapour" at each degree of Fahrenheit, and by calculation. The figures in the table representing the temperature expressed by the inner thermometer at the instant when the dew is formed, divided by the figures corresponding with the temperature of the outer thermometer, express the degree of moisture of the air. An analogous result is also obtained by another form of instrument, known as the dry and wet bulb hygrometer, in which two exactly similar thermometers are placed side by side, one having its bulb enveloped in thin muslin kept wet by water drawn out of a small bucket, or reservoir, through a wick of cotton. The wet-bulb thermometer reads lowest, on account of being cooled by evaporation from the moist muslin, and the more so in proportion as the air is more dry, and the evaporation on that account more rapid. The comparison of the temperatures indicated by the two thermometers then enables the moisture present in the air to be ascertained either by an arithmetical calculation, or by a reference to tables prepared for the purpose. The dry and wet bulb hygrometer is represented in Fig. 6.

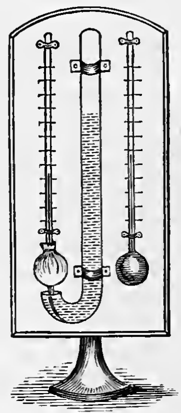
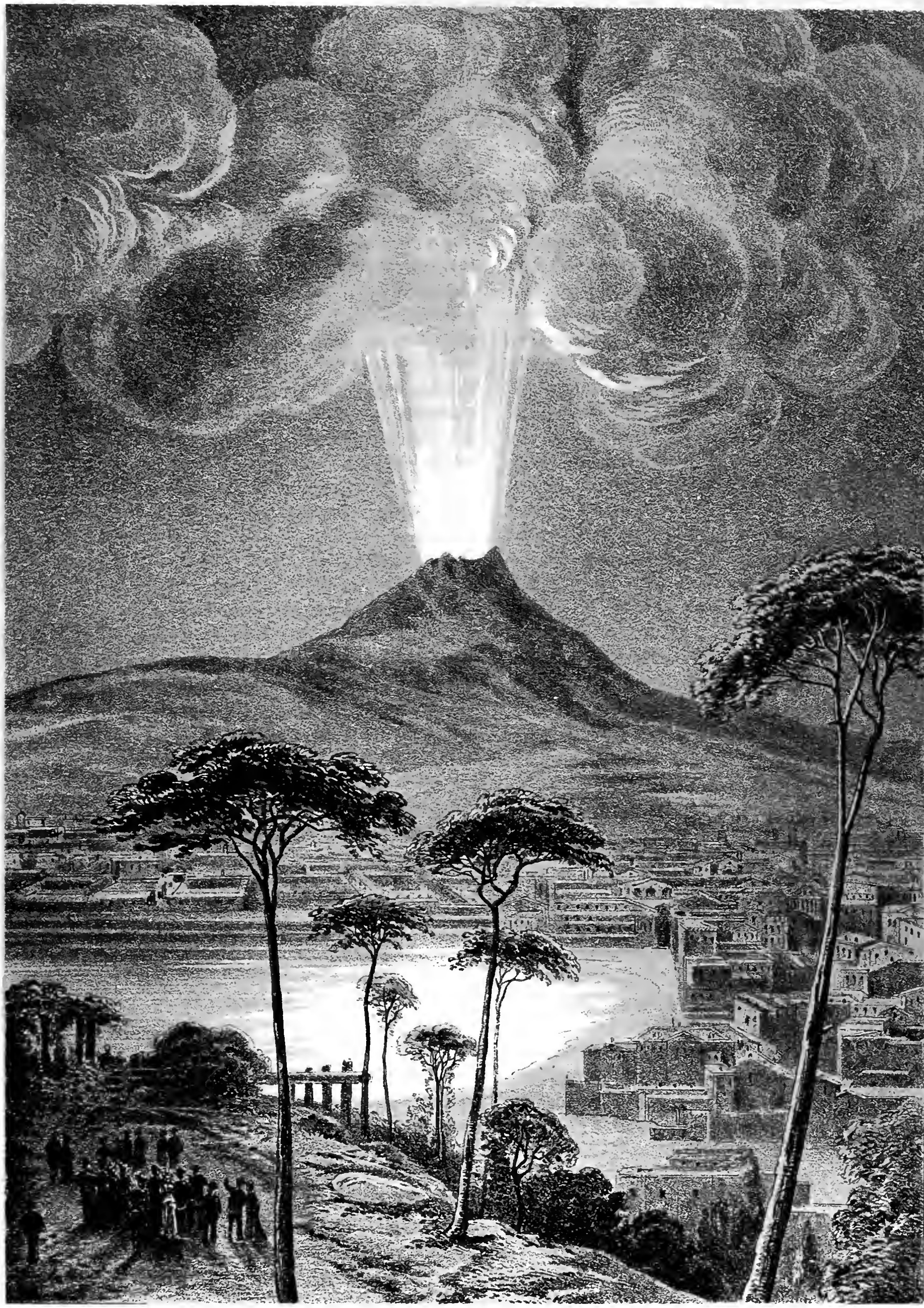


Fig. 6.—The dry and wet Bulb Hygrometer, for measuring the Moisture of the Air.



THE BAY OF NAPLES AND ERUPTION OF VESUVIUS.

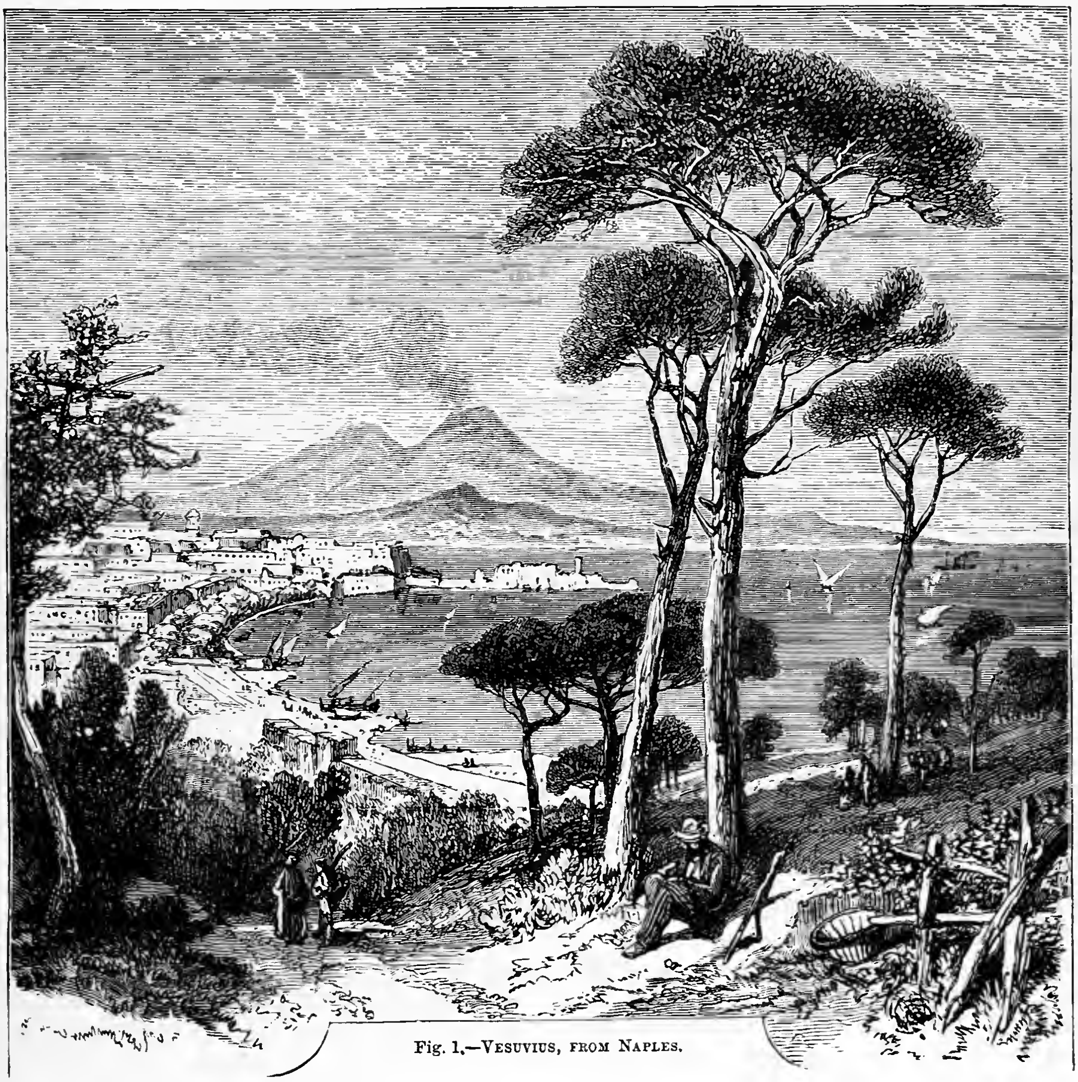


Fig. 1.—Vesuvius, from Naples.

THE STORY OF A VOLCANO AS TOLD IN HISTORY.

By Professor T. G. Bonney, M.A., F.R.S., Sec. G.S.

As the train, bound from Rome to Naples, quits at Caserta the glens of the Apennines, a lofty mass rises prominently in front of the blue line of hills stretching away to the south-east, and by its apparent isolation at once attracts the eye. Its summit is formed by a long serrate ridge, behind or on which a cumulus cloud seems to rest even on the clearest day. This is usually the traveller's first view of Vesuvius (Fig. 2); an important one, since it presents the mountain in what we may call an historic aspect—in the form which it bore when Horace was a saunterer in "easy-going Naples," and when Virgil sang the praises of "charming Parthenope."

The modern cone (for, compared with the old crater-ring of Somma, this is a thing of yesterday) is concealed from this point of view; and it is not till after some little time that a tooth on the right seems to detach itself from the rest of the ridge. This, as we proceed, gradually rises into greater prominence, and the mountain assumes the form rendered familiar to us by pictures exhibited every-

where—from the tops of work-boxes to the walls of academies—of a rather truncate cone, rising from a gently sloping base, and half inclosed on the left or northern side by a ring of broken crags (Fig. 1).

For miles the shore at the foot of Vesuvius is fringed with houses, whose white walls glitter in the Italian sun; village linking on to village, to form a gigantic arm to Naples. The lower slopes of the mountain are densely clad with the vine and the olive, the citron and the orange, yet this vesture of verdure is stained by sombre blots, which once were molten rock; the cone itself is a vast pile of dark ashes; and on these sunny villages the fire from heaven has more than once fallen hardly less fiercely than on the cities of another plain.

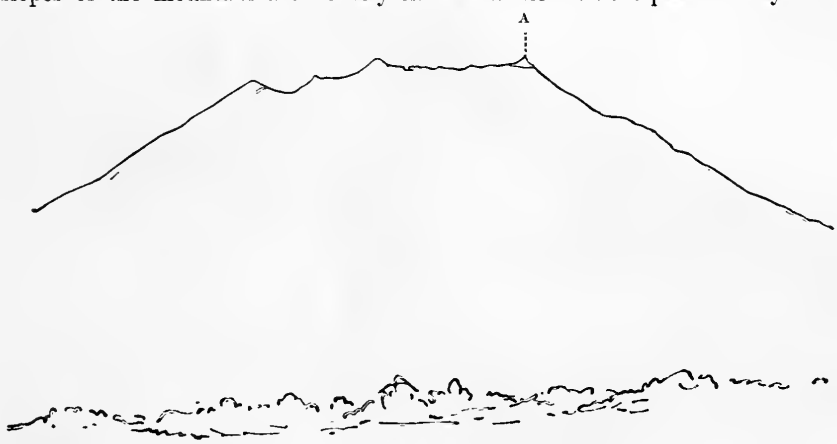


Fig. 2.—Outline of Vesuvius, from Railway near Caserta, showing the Crest of Somma and probable Form of the Mountain previous to A.D. 79. (A) Corner of Cone just coming into View.

This, then, is the story of the volcano, as it has been gathered from the records of the past by more than one author. Till full three-quarters of the first century of the present era had elapsed, we read only of dim traditions of volcanic action. To picture the mountain as it appeared in the days of Virgil, we must efface the present cone, we must restore the cliffs of Somma to an unbroken ring; and imagine, within their inclosure, a wide amphitheatre overgrown with trees and brushwood and wild vine. Once, indeed (73 B.C.), it served as a camp of refuge to a band of gladiators, who had escaped thither from the schools of Campania. Here they were for a time blockaded by Roman troops, but they scaled the cliffs by making ladders from the wild vines, defeated their foes by an attack in the rear, and so began the Servile War.

So Vesuvius remained, through all the days of which history has preserved a record till A.D. 79, a wide, circular, and perhaps rather shallow crater, overgrown with verdure, not unlike to, though loftier far than Astroni, in the neighbouring Phlegræan fields, which is now used as a royal game-preserve. The shores of the bay were studded with villages, as now, from Parthenope to Stabiæ,* probably not less numerous, certainly more opulent. We know Campania as it is, after centuries of misgovernment; then it was the "South Coast" in the palmiest days of Rome; and men took their pleasure with little stint on the slopes beloved, as the poets say, by the god of wine and the goddess of love.

The first interruption to the serenity of their life—to which a parallel may be found in the magic story of the "Water Babies"—was a violent earthquake in the year 63 A.D. For sixteen years these subterranean warnings were continued at intervals. Then came the catastrophe, many details of which are preserved for us in a letter from the younger Pliny, who, at the time, was residing with his uncle, the commander of the Roman fleet at Misenum, on the western shore of the Bay of Naples. Thus he tells the story †:—"On the 24th of August, about one in the afternoon, my mother desired him to observe a cloud which appeared of a very unusual size and shape. . . . It was not at that distance discernible from what mountain this cloud issued, but it was found afterwards to ascend from Mount Vesuvius. I cannot give a more exact description of its figure than by resembling it to that of a pine tree, for it shot up to a great height in the form of a trunk, which extended itself at the top into a sort of branches. It appeared sometimes bright and sometimes dark and spotted, as it was more or less impregnated with cinders." The old man, as he goes on to narrate, shortly after embarked for Resina, to render what help he could to the inhabitants of the towns along the coast. On approaching this, "the cinders, which grew thicker and hotter the nearer he approached, fell into the ship, together with pumice-stone and black pieces of burning rock. They were likewise in danger,

* *Modern*, Naples to Castellamare.

† Melmoth's Pliny, quoted by Phillips, "Vesuvius," p. 13.

not only of being aground by the sudden retreat of the sea, but also from the vast fragments which rolled down from the mountain." Accordingly, he changed his course a little, and landed at Stabiæ (now Castellamare), at a rather greater distance from the mountain. Though his friends there were in the utmost alarm, he took a bath and supped with calmness, and afterwards slept, until he was awakened because of the "court of his apartment being now almost filled with stones and ashes; if he had continued there any time longer it would have been impossible for him to have made his way out." After consultation, it was decided to abandon the house and make for the shore. They set forth, having tied pillows upon their heads with napkins, to protect them from the storm of falling stones. "It was now day everywhere else, but there a greater darkness prevailed than in the most obscure night." The sea ran so high that it was unsafe to embark, and shortly after, the old man fell down dead, apparently suffocated by some noxious vapour, which proved fatal to him, as he had long suffered from a difficulty of breathing. During this night earthquake shocks had been almost incessant at Misenum; and at last the relations whom he had left there quitted the house for the open country. On arriving in this, the chariots in which they rode "were agitated back and forward, so that we could not keep them steady. The sea seemed to roll back upon itself. On the other side, a black and dreadful cloud, bursting with an igneous serpentine vapour, darted out a long train of fire, resembling flashes of lightning, but much larger. . . . Soon afterwards, the cloud seemed to descend and cover the whole ocean, and the promontory of Misenum. . . . The ashes now began to fall upon us, though in no great quantity. I turned my head, and observed behind us a thick smoke which came rolling after us like a torrent; darkness overspread us like that of a room when it is shut up and all the lights extinct." Over all the land, from Sorrento to Capo di Miseno, the two horns of the Bay of Naples, this terrible hailstorm fell, till at last, when the sun shone dimly out, the ground was white with ashes as with fresh snow; and in the place of Herculaneum, Pompeii, Stabiæ, were wastes of volcanic scoria.

No lava appears to have been discharged during this eruption, or, at any rate, to have aided in destroying the town. Herculaneum is chiefly overwhelmed with a volcanic mud, formed of the finer ashes mingled with water—a material not unfrequently ejected from volcanic craters during eruption—which has now become hard and stony.

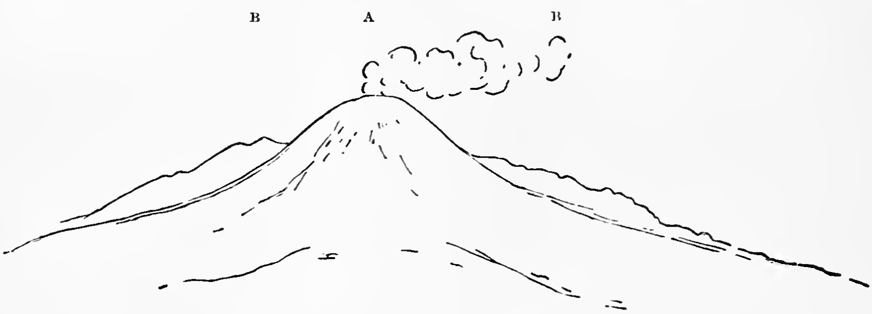


Fig. 3.—Summit of Vesuvius from Sorrento in 1876. (A) Cone; (B) Somma.

Pompeii is buried beneath light loose ashes. Subsequent eruptions may possibly have somewhat augmented these coverings; but at the present time they are in places full eighty feet deep over the former, and twenty feet over the latter.

At the close of this eruption, the aspect of Vesuvius must have been completely changed. About one-half the wall of the crater was probably blown completely away, leaving only the northern part—that now called Monte Somma—still standing (Fig. 3). A new crater was doubtless formed within the old boundary; but its cone, so far as we know, was of no great height. Eruptions occurred after this, at intervals, for some thousand years; but about the middle of the twelfth century, a period of almost unbroken repose commenced, which lasted for five centuries. It is not easy to form an accurate idea of the appearance of the mountain during this period; but probably a large, though not lofty cone existed just within the imperfect ring of Somma, whose summit it overtopped by about one hundred and sixty feet. The circumference of the rim was about two thousand yards; the interior deep and level, with three pools, fed by hot mineral springs. Vegetation had again overspread the bare rocks, as it had done previous to the outbreak of 79.

But in the year 1631 there was another awakening, hardly less terrible than the former. Again the surrounding region was shaken by earthquakes. A deep, continuous subterranean rumbling—a

common phenomenon in volcanic eruptions—was heard, till at last the fatal morning of Tuesday, December 16, dawned. Then the great pine-tree of dust and vapour—the volcano's black flag—once more rose up into the sky. Again the vapours spread, the lightning flashed, and the hail of scoria began. Great splashes of molten lava were launched into the air, and red-hot blocks fell thick about the mountain. About eleven o'clock, a fissure opened out at the base of the cone, from which fresh showers of missiles were discharged, and a stream of lava began to flow. The people of Resina fled; but those of Torre del Greco lingered till the next day, when the lava burst forth with renewed violence, "so that the whole mountain seemed to be melting." They were quitting the town in a kind of procession, when suddenly a strange noise was heard, a torrent of molten lava debouched from a side street, and poured down upon the crowd.

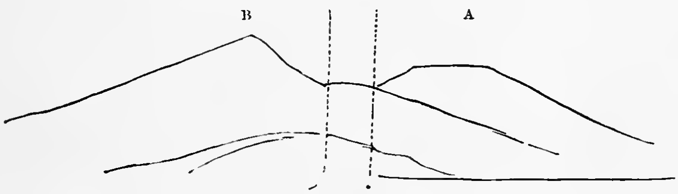


Fig. 4.—Summit of Vesuvius about 1650. (Sketched from a Picture of the Revolution in Naples in 1647. The Part indicated between dotted Lines is covered by a Chimney in the Picture.) (A) Cone; (B) Somma.

It parted; those in front escaped with difficulty; the rest found at once death and cremation beneath the fiery stream.

When at last the eruption ceased, the cone had lost about a hundred and eighty yards in height, and had increased from two thousand to more than five thousand in circumference (Fig. 4). The fertile plain of Campania was a desolate waste covered with acrid ashes. Such had been the violence of the explosion that these lay twelve palms deep at Ariano, six-and-thirty miles away; and stones of considerable size had been projected, it is said, to distances of more than sixteen leagues. Torrents of mud had injured the lands on the northern slopes of Somma, not much less than those of lava had devastated the southern slopes of Vesuvius. There, two great lava streams had been emitted—one, parting into several branches, had ravaged the country from Portici to Torre del Greco; the other the lands near Torre dell' Annunziata. Both had reached the sea in three or four places. Of the last town, only about twenty houses remained. Parts of Resina and Torre del Greco were destroyed, and probably about two thousand persons perished.

From this time, Vesuvius has seldom been at rest for many years together. Violent eruptions occurred, with the usual phenomena, and the form of the central cone was frequently changed. In the early part of 1751, the mountain was capped by an inner cone and crater, built up in and overtopping the rim of a lower crater. This was utterly destroyed in the eruption which took place in the month of October; afterwards, there remained a crater rather more than a mile in circumference, and only 120 feet deep. Successive eruptions seem to have again built up the cone, and in 1779, there was an eruption hardly less violent than that which had occurred just seventeen centuries before. Sir W. Hamilton, who has left a most minute description of this eruption, tells us that the volcano shot up a column of molten matter, like "a fountain of liquid transparent fire," to a height of full ten thousand feet. This was swayed by the wind towards Ottajano, and covered, in its fall, the whole cone with a body of fire two miles broad. This town, on the northern slope of Somma, and three miles away from the crater, well-nigh met with the fate of Pompeii; the ashes lying in the streets as much as four feet deep. In 1794, there was an eruption hardly less violent, as the lava flowed through Torre del Greco to the sea. In 1822, the greater part of the central cone was engulfed, and its rim, instead of rising above the edge of Monte Somma, stood from three to four hundred feet below it. Since that time it has again been built up, and at present is about 4,250 feet above the sea, and nearly 500 above the highest part of Somma, and about 1,700 above the Atrio del Cavallo. The annexed diagram (Fig. 5) represents its outline in 1876, and a comparison with the previous one, and of both with that near the beginning of this article, will give some idea of its changes in form. The last of these (Fig. 2) probably represents the mountain much as it appeared previous to A.D. 79; Fig. 4, its form after the eruption of 1631, and again after that of 1822.

Such is the story of Vesuvius, one which may stand as a type for that of many volcanoes, illustrating the mode in which they are formed. Once it was thought that comparatively little of a crater was constructed of the piled-up scoria and lava driblets ejected from its orifice, but that when this opened, strata previously horizontal were elevated in a conical form around it, by the upward pressure of gases and lava struggling to escape. Now it is

held that such elevation takes place to but a slight degree, if at all, and that the greater part of a volcano is composed of the materials which it has vomited forth. In the story of the cone of Vesuvius—built up from the floor of Somma to a height of full five hundred yards, and more than once almost wholly destroyed, and reconstructed—we see what the volcanic forces are competent to perform; and when, after examining the structure of the cone, with its driblets and dykes of lava and its irregular layers of scoria, we wander below the crags of Somma to the Atrio del Cavallo, or seek the ravines which the rills of rain-water have worn in its flanks, we notice that neither the lava-beds nor banks of ashes are regularly arranged or have a uniform slope, but present the same characteristics as those in the modern cone. We see that the flows of lava have not spread themselves out on level ground and then been tilted up, but have run irregularly, in driblets and clinkery streams, as if they had solidified on a slope, and that both they and the beds of scoria quickly change their character when traced horizontally.

Fig. 5.—Vesuvius, from near Naples, in 1876.
(A) Cone; (B) Somma; (C) Pedimentino, Site of destroyed Part of Crater; (D) Hermitage; (E) Lava Streams.

Thus, in the history of Vesuvius—which is confirmed by that of every other volcanic mountain which has been carefully studied—we find evidence to show, beyond reasonable doubt, that a volcanic mountain is its own architect.

CAN SCIENCE CONQUER RUST?

By F. S. Barff, M.A., Christ's College, Cambridge.

King.—" And is not this an honourable spoil?
A gallant prize?" . .
Westmoreland.—" In faith,
It is a conquest for a prince to boast of."
First Part of King Henry IV., Act i., Sc. 1.

It has been seen in a former article (pp. 41—47) that the action of rust is so destructive to iron, from the nature of the chemical process on which it depends, that a method for its prevention is much to be desired, and it will, therefore, be not uninteresting to discuss this important question.

A few words will be sufficient on the oldest, perhaps, of all methods of protecting iron—viz., painting. Paint is made of some solid substance, generally the oxide or carbonate of a metal, mixed with oil and turpentine, with oil alone, or with some kind of varnish, which varnish is

composed of a gum-resin, oil, and turpentine. Other paints than these have been recommended and used, but they are specialties, some of known, others of secret composition. When an oil paint is used, its protective action depends upon the hardness which it acquires, and on its power of adhering to the surface of the iron. If a paint could be made which would always adhere firmly and have sufficient hardness, nothing more could be required, because it would always preserve the surface of the metal from the action of atmospheric oxygen; but it has been found that no paint has ever been able to effect this object, as the oil at first becomes hard by oxidation, and afterwards is slowly destroyed by the same oxygen which gave it a temporary protecting power. Again, certain metallic oxides mixed with the oil have an injurious action on the iron itself, whereas some seem to exert, for a time, a preservative influence. Well-made varnishes harden almost immediately after application, but they in time disintegrate, and allow the pigments mixed with them to crumble off. It is not to any organic substance, such as oil or gum-resin, that we must look for arresting rust on the surface of iron, as all organic substances decay when exposed to the action of moisture in conjunction with oxygen. If only a temporary protection for iron be required, paint will answer fairly well, but as a permanent preventive of rusting it is simply useless. Certain compounds are advertised and sold which are stated to protect iron effectually. Now, if such substances contain organic matters, although they be mixed with silicates or other mineral substances, which may increase their power of resisting decay for a time, still, sooner or later, the same process of disintegration will destroy the power of cohesion among their particles, and so cause them to fall off from the surfaces to which they have been applied. It is to something more enduring than paint that we must look for effecting the important object into which we are inquiring, for nothing short of a mineral substance can possibly prevent iron from rusting, and a mineral substance, too, which, whether elementary or compound, is able itself to stand against the action of those agents to which the iron can be exposed.

It will be remembered by those who have read the article on "Rust" that it was stated that zinc, when covered with a film of white oxide, if exposed once to moist air, did not further oxidise, and therefore remained unchanged. On account of its possessing that property, it has been used for the protection of iron. The process in which it is employed is termed galvanising; but before describing it, it will be well to consider the very interesting chemical principles on which it is based. Some metals are what is called chemically more powerful than others, and therefore are able to displace them from and replace them in certain compounds. A very good illustration of this is afforded by the lead-tree. If some acetate of lead be dissolved in distilled water and be left to stand, should it be at all turbid, till it gets clear, and be then poured carefully into a white physic-bottle, and if a small piece of zinc be suspended by a string attached to the cork used for stopping the bottle, and the zinc be allowed to hang in the solution of acetate of lead, very soon beautiful arborescent crystals of metallic lead will adhere to the zinc, and in time the bottle will be filled with what is called a lead-tree, always supposing that sufficient acetate of lead has been dissolved in the distilled water. In this case we have in solution acetate of lead and solid zinc. Zinc is chemically more powerful than lead, and causes the lead to be deposited in the metallic state, or throws it out, so to speak; but the zinc is dissolved up, and takes the place of the lead—that is, becomes acetate of zinc. If sixty-five grains of zinc be hung in a solution containing three hundred and seventy-nine grains of acetate of lead, all the lead would be deposited as metal, and all the zinc would be dissolved up as acetate, so that no metal but zinc would be found in solution by chemical tests. Again, if the bright blade of a knife, or any iron or steel articles, were placed in a solution of sulphate of copper, they would immediately be coated with copper. Part of the iron being dissolved up would take the place of the copper deposited, and become sulphate of iron. For every 63·5 parts by weight of copper deposited, 56 of iron would be dissolved up, and this would take place because iron is chemically more active than copper. In scientific language, iron is said to be *electro-positive* to copper; zinc is electro-positive to iron—that is, it has greater chemical activity. If a plate of iron about an inch and a half wide and three inches long be placed in a glass containing water acidulated with oil of vitriol, bubbles will be seen to form on its surface and ascend through the water. These bubbles are formed by hydrogen gas, which is given off by the decomposition of the oil of vitriol; and if this action be allowed to go on long enough, all the iron will be dissolved, and, taking the place of the hydrogen set free from the oil of vitriol—or hydric-sulphate, as it is called by chemists—

will form iron sulphate. Now, suppose a copper wire to be fixed to one end of the piece of iron, and a piece of zinc similar in shape and size to the iron be fixed to the other end of the copper wire, and both pieces to be immersed in the dilute oil of vitriol, the bubbles of hydrogen will still be seen to come from the iron plate, but it will not be dissolved. The zinc plate will gradually disappear; and until it is dissolved and converted into zinc sulphate, the iron will remain comparatively unaffected. Some iron will be dissolved, but not much. The apparatus necessary to perform this experiment is very simple; it is shown in the accompanying illustration (Fig. 1). From this it appears that in the presence of dilute acid the zinc, at its own expense, protects the iron, and it protects it in this way: it is chemically more powerful than the iron, and therefore is oxidised and dissolved by the oil of vitriol before the iron is affected. Now, the stronger the solution of oil of vitriol, within certain limits, the more rapid will be the action; and, of course, the weaker the solution, the slower will be the action. It is known that in the air there are substances which produce a similar effect on these metals. We have already seen in the article on "Rust" that air and moisture produce it on iron, and that they also produce it on zinc. Now, when these metals are united, as they are in the galvanising process, these destructive agents attack the zinc first, as in the experiment described, and the iron is protected by the zinc as long as it lasts. This, though theoretically, is not practically the case to the full extent. It is true that the zinc does for a time protect the iron in this way, but when parts of the iron get laid bare they rust, although a large quantity of zinc remains in contact with the iron. When oxidation of the iron does commence in galvanised iron, its progress is rapid, as it extends under the surface of the zinc coating and throws it off, thereby exposing more iron surface to the rusting action; and as it is seldom thought necessary to paint galvanised iron, the process of decay usually goes on unchecked.

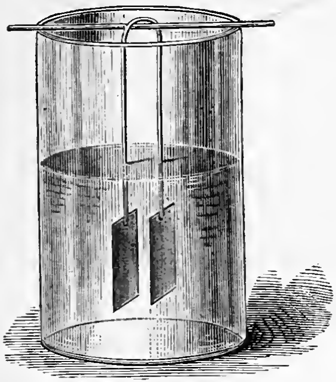


Fig. 1.—Showing Action of dilute Oil of Vitriol upon a Zinc and an Iron Plate.

Coating iron with tin, or "tinning," is another method supposed to be used for its protection. If the experiment already described be again performed —with this difference, that a piece of tin be substituted for the zinc plate—it will be found that the iron will be first dissolved and the tin will remain. The tin used should be grained tin, not tin plate, for tin plate is only iron coated with tin; but even with tin plate the action may be illustrated, for if the tin be removed from the surface of the plate in places, and if it be placed in dilute oil of vitriol, the iron will be dissolved out and the tin will be left. Here the tin affords no protection to the iron in the same way that zinc does; it only protects it against the action of substances which affect iron, but do not readily affect tin, by keeping it covered up. Whenever the tin in places gets removed, the iron exposed to the action of destructive influences goes first, and more rapidly because it is tinned. Tinned iron is never used for outside work; it is mainly employed for articles of domestic use, and particularly for saucepans, in which substances are placed, often of acid character, which would directly attack iron, but have little or no effect on tin. Cast-iron saucepans and wrought-iron stewpans are tinned inside only, and this for the same purpose. From what has been said it will be seen that neither tinning nor galvanising can afford a permanent protection to iron against rust.

For purposes in which durability is required, it is manifestly important that iron should not be brought into contact with other metals when it is to be exposed to the action of air and moisture, for it will suffer by the contact. If we examine the old iron railings placed round the gardens in some of the squares in London, we shall find that they have decayed away close to the stone in which they are imbedded. Sometimes for three or four inches they taper downwards, and become very thin where they meet the stone; but the fastening which holds them in their sockets will be found to be perfect. Now, this fastening is lead, and iron is electro-positive to lead, and therefore the lead has caused the destruction of the iron. That this is the case may be proved by substituting lead for tin in the experiment before described.

Enamelling is another process which has been applied to iron to preserve it from rust. Enamels are glazes of various degrees of fusibility, and are composed of silica, or sand, an alkali, and one or more metallic oxides, according to the quantity of alkali used and the nature of the metallic oxides;

the enamel is made more or less fusible. Borate of lead is often used to increase the fusibility of enamel, and sometimes in place of silicate. In applying the enamel it is reduced to a fine powder, and floated or painted on to the iron surface, which is then raised in a closed muffle to a sufficiently high temperature to melt the enamel, which, when cold, adheres to the surface of the iron. Saucepans and various articles of domestic use are treated in this manner, and signs, advertisement plates, &c., of enamelled iron are largely used. For many purposes the process answers exceedingly well, but where there is any wear, as in the case of saucepans, the enamel in time comes off, and then the exposed surface of the iron rusts, and the rust, extending beneath the enamel, throws it off, so that the protection it affords in such cases is but temporary: for, in whatever way the enamel is broken, the consequences just alluded to are sure to follow. If any oxide of lead be put into the enamel, which is sometimes done, it renders it unfit for articles used in cooking, or in the preservation of food, as acids act on the oxide of lead, and by dissolving it, cause it to mix with the food; and lead taken into the system is a dangerous poison. Nor does it suit for water-pipes, as pure water (and even impure water), slowly dissolves oxide of lead. Enamelled articles often crack, through the unequal expansion and contraction of the enamel and the metal.

I will now proceed to describe a method for the preservation of iron from corrosion, of which I have had several years' experience, and which does, I believe, completely effect the desired object. In the article on "Rust" I mentioned an oxide of iron which is perfectly unchangeable under the influence of those agencies which produce ordinary red rust. The black or magnetic oxide of iron is not affected by moisture, atmospheric air, or sea-water, as is proved by the unaltered condition of that substance which is found in the form of sand on the sea-shore in New Zealand, as stated in the article above alluded to. This black oxide of iron can be artificially produced in several ways; by heating iron in air for instance. If a piece of bright iron be made red-hot in air, it becomes black; and if the operation be repeated several times, the black surface will scale off if the iron be gently tapped. Black scales are seen in quantities round the anvil of the blacksmith; these scales are not iron, but black oxide of iron. Again, if water be thrown upon red-hot iron, on cooling a black coating will be formed on parts of its surface; and if the iron be exposed to air, it will rust only in places where the black coating has not been formed, and where it has been imperfectly formed rust will appear only after a longer time; this coating is also one of the black oxide. In preparing hydrogen gas in quantity, scraps of iron or iron-filings are sometimes placed in an iron tube and made red-hot; steam is then passed into the tube, and hydrogen gas passes out at the end opposite to that at which the steam enters. This can be easily proved by experiment. The accompanying illustration (Fig. 2) shows the nature of the apparatus which should be employed. The same experiment can be performed in a more simple way by those who have not chemical apparatus at hand. If a piece of iron gas-tube be bent so that the bent part can be put into an ordinary fire, if the bend be filled with small pieces of iron—garden nails broken will do very well (they must not be rusty)—if a cork be fitted tightly in one end of the tube, which should project some foot or more from the grate, and if into a hole in this cork a piece of glass tube be fitted quite tightly, and be then connected with the spout of a kettle by means of a piece of india-rubber tube, the steam will pass from the kettle through the iron tube and come in contact with the red-hot iron, by

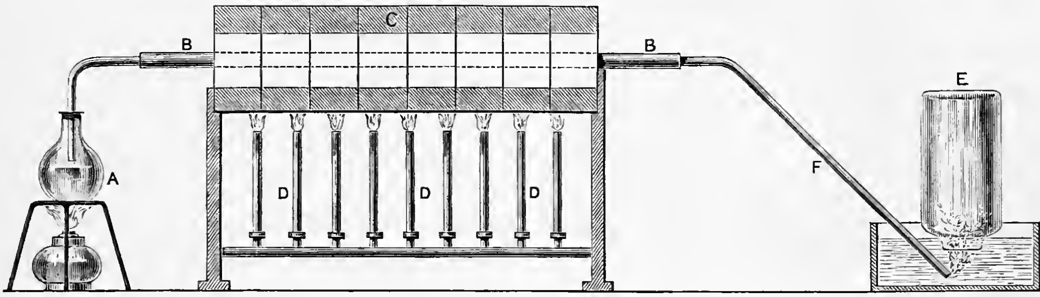


Fig. 2.—Apparatus for Preparing Hydrogen Gas.
(A) Flask of Water boiled by Spirit Lamp; (B B) Iron Tube, in which are placed Iron-Filings or other Iron Fragments; (C) Inclosure of Fire-bricks; (D D D) Bunsen Burners to heat ditto; (E) Bottle inverted in Trough of Water to receive Hydrogen from Tube F.

which it will be decomposed, and the hydrogen of the steam will pass out at the other end of the bent gas-pipe. If a light be applied to it, if too much undecomposed steam does not pass out with the hydrogen—and this can be regulated by not letting the water in the kettle boil too violently—the hydrogen will take fire; or — what is perhaps a better plan—the hydrogen can be collected over water, as in the illustration; the only thing necessary to be done is to put a similar cork and piece of glass tube into the other end of the bent pipe, and to lead it by means of a piece of india-rubber tube into the vessel of water over which the hydrogen is to be collected. If in either case the iron placed in the tubes be examined, it will be found to have changed colour—it will be black; if the iron, before it is exposed to the action of the steam, be made quite clean, this change will be more easily perceived. In these cases the oxygen of the steam has united with the iron, forming the black or magnetic oxide whose composition was given in the paper on "Rust." If the pieces of black iron be now exposed to moist air, and at the same time other pieces be also exposed which have not been submitted to the action of hot steam, they will be found not to rust nearly as quickly as the others, but in a short time they will rust; so that the black oxide of iron does not protect iron from rusting unless it be made to adhere very closely to its surface, and this it never does when formed in the way above described.

In order to explain this fully, it will be well to consider, first, the nature of steam. We are accustomed to say that we see steam escaping from the mouth of a tea-kettle in which water is boiling briskly. Now this is not correct; we cannot see *steam*, because it is a transparent, colourless, and therefore invisible gas. If a small quantity of water—a drop or two—be placed in a clean glass flask, and if the flask be heated to a temperature of over 100° C., or 212° Fahr., the water will be converted into steam, and nothing will be seen in the flask; but if it be allowed to cool, a sort of mist will be seen inside it, for the steam will condense, and will be eventually, as the flask cools, deposited on it in small drops of water. When steam is heated beyond the temperature at which it is formed, it expands like any other gas, and is completely dry. If the hand be passed quickly through a stream of it issuing through a pipe it does not wet the hand, nor does it scald it; whereas, if the hand be passed through what issues from a boiler or a kettle-mouth it is wetted and scalded. This is one way by which we test whether steam is dry or wet; another is by looking to see if the vapour is at all visible; if it is, the steam is not dry. In the article on "Rust" it was explained how air can hold water-vapour in suspension; all gases can do the same, and steam amongst the number; therefore we can have wet steam or dry steam. The steam used in steam-engines is wet steam, because it is generated in the presence of water, for the boiler always contains water, more than enough to generate steam required at the time, and when this escapes into the air it is immediately condensed, with the water-vapour which it holds in suspension; and what is seen is not steam, but water-vapour condensed into minute drops of water. Now, wet or moist air produces rust, or red oxide of iron, more rapidly in a warm than in a cold place, and as the temperature increases the action becomes more rapid; therefore, when iron which is very hot is kept for a short time in an atmosphere of moist steam, the red oxide or rust is found on its surface. I must now leave this part of my subject for a short time.

If red oxide of iron be placed in a tube, and if it be made hot, hydrogen gas passed through it will take away its oxygen, and pure metallic iron will be left in a state of very fine division. This experiment is so interesting that I will explain how it can be performed. The apparatus necessary somewhat resembles that which is used for the production of steam by metallic iron. Instead of the vessel for generating steam, use one for evolving hydrogen, and in the long tube, which in this case may be of glass—"hard glass," as it is called—place the iron-rust, or red oxide. If there is any difficulty in getting enough of this, dry Indian red, which can be bought at any ordinary paint-shop and is very cheap, will answer the purpose; for although it may not be all oxide of iron, being perhaps adulterated with other substances, yet there will be enough oxide for this experiment. Instead of the apparatus required to collect hydrogen described in the former experiment, it will be simply necessary to conduct the pipe at the extreme end of the tube into a small glass vessel—a large test-tube will do very well, and this test-tube should be placed in a vessel of cold water, so that the steam as it issues may be condensed. I will now describe the apparatus for generating and drying the hydrogen. First, take a bottle, as shown in the illustration (Fig. 3), through the cork of which is placed a tulip-shaped funnel *a*, called sometimes a thistle-funnel, the end of whose tube should dip beneath the fluid in the bottle; then a short bent delivery-tube *b* should be put just through the cork; a second bottle

for drying the gas, arranged as shown, should be connected by an india-rubber coupling with the generating bottle; and the tube conducting the gas into it should reach nearly to the bottom; into this

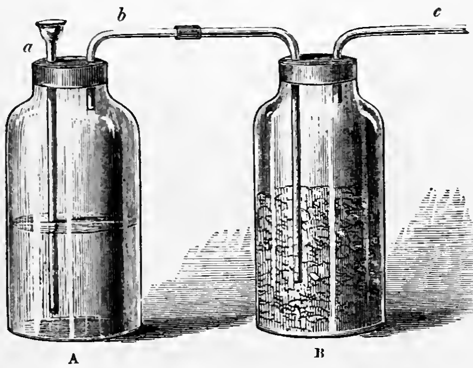


Fig. 3.—Apparatus for generating and drying Hydrogen.

bottle B small pieces of pumice-stone should be put, and these should be moistened with strong oil of vitriol, and a small quantity of oil of vitriol, to the depth of an inch, should cover the bottom of the inside of the bottle. It will be remembered that the tulip-shaped funnel was illustrated in the paper on "Rust" (Fig. 2, p. 42), and that the action of oil of vitriol in absorbing moisture was explained. Let the end of the pipe *c* be joined by an india-rubber connecting-tube with the small pipe inserted in the end of the long hard glass tube containing the oxide of iron. Dilute some oil of vitriol with water, about one part to six or eight of water by measure, stir them well together with a glass rod, and leave the mixture to get cold; then put into the bottle A some granulated zinc, or small pieces of sheet-zinc, and having corked it tightly up and made all the joints of the apparatus tight, pour in through the tulip-funnel the cold mixture of water and oil of vitriol; effervescence will take place, and hydrogen will be given off, which will be dried by the oil of vitriol in the bottle B; it will then pass through the oxide of iron, and out at the end of the last delivery-tube.

If any air were left in the bottles along with the hydrogen, an explosion would take place when the long tube containing the oxide of iron was heated. To avoid this, collect some of the hydrogen from the delivery-tube by holding it upright, with a test-tube inverted over it—*i.e.*, with its mouth downwards. Still holding the test-tube in the same position, remove it carefully from the delivery-tube, and apply a light to its mouth. Should the gas light quietly, with only a slight sound, and if the hydrogen burns quietly, all is safe, and you may light the gas-burners beneath the tube containing the red oxide of iron; should, however, a shrill sound be produced on application of a light, wait a few minutes, and then repeat the experiment, for the shrill sound bespeaks the mixture of air with the hydrogen, and proves that it is not safe to heat the tube. In this experiment, where so high a temperature is not required, two burners, called Bunsen burners, which can be bought for a few shillings, will answer the purpose for heating the oxide of iron instead of a gas furnace, such as is shown in Fig. 2.

In this experiment, the oxide of iron will be reduced—that is, its oxygen will be taken away, and metallic iron will be left; now suppose this iron were immediately transferred to the tube shown in apparatus (Fig. 2), and if it were heated, and if steam were passed over it, it would be converted into the black or magnetic oxide. Now let us consider what would take place in a hot chamber if iron were submitted to the action of wet steam: red oxide would at first be produced on its surface, and hydrogen would be set free in abundance; this hydrogen, at the temperature, would reduce the red oxide formed, and leave it as metallic iron in fine division on the surface of the iron being acted upon, and this iron, as the steam got dry from its being heated to a higher temperature in the chamber, would be converted into black magnetic oxide, but its particles would be loose on the surface of the iron. And then the process would go on, and the whole surface of the iron would be converted into black oxide, which would hold down these small particles, but which would not bind them fast together and to the surface of the mass of iron, and therefore there would not be perfect coherence between the particles of the coating, nor would it adhere firmly to the surface of the iron. But, as we have seen, a perfectly hard and adherent coating only can permanently protect the iron, so that *this* would not do it, for on exposure to friction it would rub off in places, and the iron, under the influence of moisture and air, would rust.

In the earlier experiments to make the black oxide form a permanent protection for iron against rust, this difficulty was encountered, and for a long time it seemed impossible to get over it, until its cause was discovered, and then the remedy became simple, though it took a long time to find out how best to apply that remedy. It may be interesting to explain how the cause was discovered. A piece of iron, after a short exposure to the wet steam, was accidentally taken out of the hot chamber, and

found to have patches of red oxide upon it—or rather, brown oxide, for it was in process of reduction to the metallic state. An examination at once set the operator a-thinking why this should be, and he was led to a conclusion which was subsequently confirmed by repeated experiments to be a right one. And here let me remark that no training that I know of is equal to the study of chemistry, practically carried out, for sharpening the powers of observation first, and of reasoning upon the facts observed. To remedy this defect in rendering the coating of black oxide adherent to the iron, recourse was had to super-heated steam with complete success. The steam was generated in a flask, and was then passed through a coil of pipe, placed in the furnace, which became red-hot; the steam in its passage through the coil became dry—that is, all vapour of water taken up by it in the generating flask was converted into true steam, or water-gas, and this, at a high temperature, came in contact with the iron to be acted upon, which was placed in another chamber connected with the red-hot coil of pipe. The iron oxidised in this way was found to be covered with a film which adhered closely to it, and which could be removed only with great difficulty; on exposure to water and moist air it did not rust, and thus the problem of rendering the black oxide of iron suitable for the protection of iron against rust was solved. The apparatus used in these experiments was not suited for application to oxidising larger pieces of iron; and it may be interesting, as the process is quite new, to show the various forms of apparatus which have been used during the progress of this invention to bring it to such a condition as would render it useful in commercial undertakings.

Our illustration (Fig. 4) shows the form of the super-heater and oxidising chamber which was first used. The super-heater was also the generator of the steam—the coil of pipe placed in an iron furnace answered this double office; when the furnace was at work the pipe became red-hot, the lower end of the coil was connected with a cistern placed about thirty-four feet above it, and water under this pressure was allowed to enter the hot coil. The water which first came in contact with the red-hot iron was converted into steam, and this, with the water pressure behind it, was forced through the red-hot coil, and became super-heated; the place of this steam, as it escaped, was taken by other steam formed in a similar manner, so that the current of super-heated steam issuing from the other end of the coil was continuous as long as the water-supply lasted; the issuing steam was allowed to escape into an iron chamber or muffle, which was heated by a fire beneath it, which played

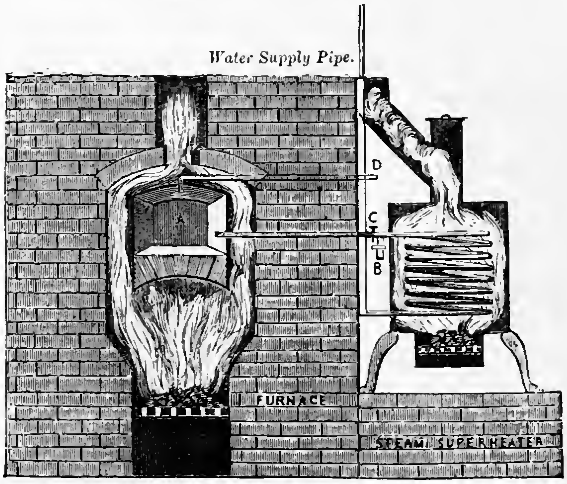


Fig. 4.—Form of Super-heater and Oxidising Chamber which was first used.

(A) Muffle or Chamber, inclosed by Door; (B) Test Tap; (C) Steam Admission Tap; (D) Hydrogen Outlet Pipe.

around and above it by means of flues placed in the brick-work in which it was set; the muffle was closed by an iron door, in which there was a small tube fixed, through which excess of steam, and the hydrogen formed in the process, could escape. The hydrogen as it escaped was often ignited, and it burned with the characteristic non-luminous flame of hydrogen.

After this apparatus had been used for some time, a very much larger one on the same principle was made, the muffle or oxidising chamber being still of iron. After a time, it was found that this kind of super-heater was not applicable to work which had to be conducted on a commercial scale, for in coaling the fire which heated it the super-heating coil was often chilled, and thus wet steam was projected into the muffle; this was injurious to the coating, as has been explained. On several occasions the pressure of water was not sufficient, and air got into the muffle; this, too, interfered with the adherent properties of the black oxide; it was therefore found desirable to change the form of the super-heater, and to generate the steam in a separate boiler. This plan has been tried, and is found to answer very well. In order to prove the possibility of oxidising very large pieces of iron, the new chamber was built of fire-bricks, and as this has succeeded well, a chamber of any size so constructed, and which can be raised to a sufficiently high temperature, can be employed.

Iron chambers could not be made sufficiently large, or rather, would be very expensive if made large enough to oxidise very large articles. In Fig. 5 is shown a convenient form of apparatus, and one very similar to that which has been in use for some time. A is the oxidising chamber, B the boiler, C the super-heater, and *b* the tube which conducts the steam from the boiler through the super-heater. The steam need be under no greater pressure than ten pounds. The super-heater coil contains about forty feet of inch iron pipe; it is protected by fire-tiles at the sides and by fire-clay above, so that the iron may not be exposed to the direct action of the flames, which would cause its somewhat rapid destruction. The super-heated steam passes through the pipe C into the oxidising chamber A, and the excess of steam and hydrogen escape by the pipe *d d d*. In conducting the process, the chamber A is heated by the fire beneath it, the heated air passing through flues built up its sides, which meet in an open space above the arch, and this space is again covered by another arch of brickwork which is in connection with a chimney about thirty feet high; when the chamber A is at a temperature of about 500° Fahr., which is sufficient to prevent the condensation of the steam, the chamber is charged with the iron to be treated; it is then closed, and is allowed to arrive again at the same temperature; the super-heated steam is then turned in, it being at a temperature of 1,000° Fahr., or even higher; in a short time it makes the iron articles in the chamber red-hot, and coats them with the black oxide. The time during which the process is continued differs according to the bulk of the articles to be oxidised: from five to ten hours is about the limit. The operation, after a little experience, can be carried on with certainty. This process is applicable to almost every sort of article; and the results of experiments carried out by competent people, extending over a space of upwards of two years, show that iron, properly treated, does not rust even

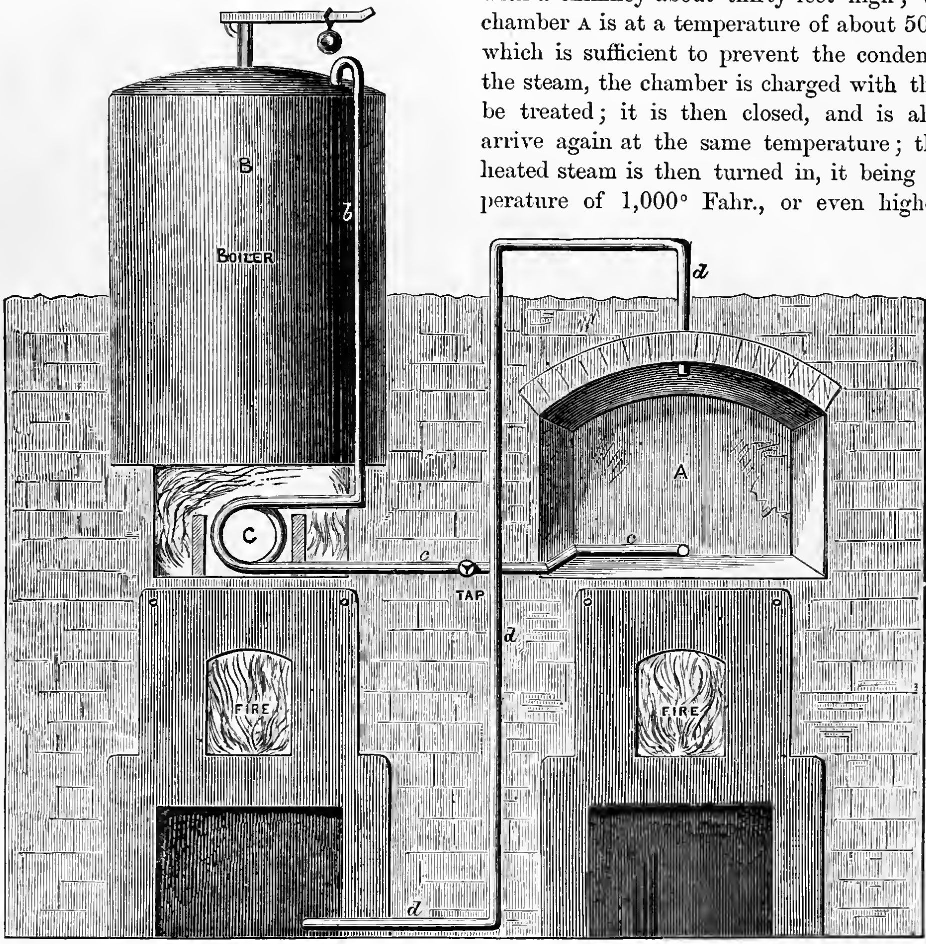


Fig. 5.—APPARATUS FOR OXIDISING IRON.

(A) Chamber, or Muffle, in which the Iron Articles are placed; (B) Boiler; (C) Super-heater—a Coil of Pipe supplied with Steam from B by Pipe *b*, and passing into Chamber by Pipe *c*; (*d d d d*) the Pipe to allow of the liberated Hydrogen escaping, and which is conducted into the Ash-hole under the Fire, and assists the Combustion of the Fuel. (The one Fire heats the Super-heater and the Boiler.)

when exposed to very severe tests, such as the action of sea-water, acid vapours in laboratories, and other agencies, which in a few hours rust unprotected iron. Pipes which have been buried in the earth for a long time have been found to be perfectly free from rust when examined.

HOW THE AIRS WERE DISCOVERED.

By William Ackroyd, F.I.C.

THE gaseous state of matter is one of extreme interest. It is believed to be the present condition of many of the stars; it may have been the first condition of the earth;* and now that the latter has cooled down to a solid habitable globe, it is still invested by a gaseous envelope (the air), and has very many kinds of gases issuing from its vent-holes (the volcanoes). In the present paper we propose to add a little more to what the reader already knows about these gases, and only a little; for to give a full account of all that is known would require very much more space than that allotted to us.

Rather more than a century ago, nothing much was known about these gases, or airs as they were termed; but soon was found out one of their most remarkable qualities—*solubility in liquids.* To gain clear notions, watch for a moment a very familiar operation. A lump of sugar is put into a cup of tea. Soon it disappears: it has been dissolved. We accordingly say that sugar is soluble in tea, and it furnishes us with an example of a solid dissolving in a liquid. Instead of sugar, we might have put in treacle, which likewise would have soon disappeared, giving us an example of a liquid dissolving in a liquid. We shall now give some examples wherein gases disappear upon coming in contact with the surface of water, showing their solubility in this liquid.

Ammonia gas is one of the most remarkable on this account, for as soon as ever it is brought into contact with water it disappears, because the water absorbs or dissolves it so readily. The spirits of hartshorn sold by druggists is a solution of this gas, and the ammonia may be driven from the hartshorn in the following way. Let the spirit of hartshorn be placed in the flask *a*, in the neck of which a tightly-fitting cork is placed, with a delivery-tube *b* passing through the cork at one end, and dipping into the trough *e* at the other. The flask *a* rests on wire gauze, and under it is placed a Bunsen burner. The trough *e* contains mercury or quicksilver, and the vessel *c d*, with its open mouth downwards, is full of it. As the flask *a* is heated, ammonia gas passes down the delivery-tube *b*, and if the end of the tube dips

Fig. 1.—Experiment demonstrating how Ammonia Gas may be obtained.

under the vessel *c d*, the latter will soon be filled with ammonia gas. We shall explain this method of catching gases more minutely a little farther on. Next remove the end of the delivery-tube from the trough *e*, and then take away the Bunsen burner.

Now that the jar *c d* is full of ammonia gas, some of its properties are very evident to us. We see that it is transparent and colourless. Stray bubbles of it have made us aware of its peculiar and pungent smell; but the property which we wish to impress upon the reader can only be rendered evident by another simple experiment. Place a plate of glass over the mouth of the jar *c d*, and now remove the jar and its contents to a basin of water, placing it in precisely the same position in the basin that it occupied in the mercury trough—*i.e.*, with the mouth downwards and the end *c* upwards. This being done, remove the plate of glass from the mouth of the jar, and so allow the ammonia gas to come in contact with the water. In far less time than one takes to tell it, the water has rushed up into the jar. So soon as ever the ammonia gas

* "Science for All," Vol. II., p. 116.

was exposed to the surface of the water, the latter dissolved it eagerly, the gas disappeared, and external pressure forced the water up into the jar to supply its place.

Gases, then, are soluble in water, but exact experiment has shown that they dissolve in widely different degrees. We have some accurate data on this subject given by the German chemist Bunsen. He has shown, for example, that a pint of water will dissolve 1,180 pints of ammonia gas at the temperature of melting ice (0° C.).* The following table shows how many pints of each of the gases named are dissolved by one pint of water at this particular temperature.

Modern Name.	Ancient Name.	Number of Pints dissolved at 0° C. by 1 Pint of Water.
Ammonia	Alkaline air	1180
Hydrochloric acid	Marine acid air	505
Sulphurous anhydride	Vitriolic acid air	53·9
Sulphuretted hydrogen	Stinking sulphureous air	4·37
Carbonic acid or anhydride	Fixed air	1·80
Hydrogen	Inflammable air	0·019
Nitrogen	Foul air	0·020
Oxygen	Empyreal or dephlogisticated air	0·041

Of all these gases, it will be seen that ammonia is by far the most soluble, and that hydrochloric acid stands next in order. The spirits of salt of commerce is a solution of hydrochloric-acid gas in water, just as spirits of hartshorn is a solution of ammonia in water. If we were to place spirits of salt into the flask *a* (Fig. 1) instead of the hartshorn, and then to heat with the Bunsen burner, we should obtain hydrochloric-acid gas in the jar *c d*, as we before obtained ammonia.

From the experiments with the ammonia we learn two broad facts: (1) that a gas is readily absorbed at a low temperature; and (2) that some of this gas is again expelled at a higher temperature. This disengagement of gas when a solution of it is heated may be explained in the following way:—A liquid will not absorb so much gas at a high temperature as it will at a low one; and as a matter of experiment we know that, although a pint of water will absorb 1,180 pints of ammonia at 0° C., it will only absorb 444 pints at 40° C. If, then, we had a solution of ammonia (water, so to speak, *filled* with ammonia gas) at 0° C., and if we were now to heat it up to 40° C., roughly speaking three-fifths of the dissolved gas ought to be given off, because of the decreased dissolving power of the water, owing to the rise of temperature.

The amount of decrease of absorption has been ascertained for many gases. The first line of accompanying figures shows how many pints of gas a pint of water absorbs at 0° C.; the second line of figures shows how many pints of the same gases are absorbed at 20° C. A decrease will be noticed in every case, save that of hydrogen.

Temperature.	Ammonia.	Hydrochloric Acid.	Sulphurous Anhydride.	Sulphuretted Hydrogen.	Carbonic Acid.	Hydrogen.	Nitrogen.	Oxygen.
0°	1180	505	53·9	4·37	1·80	·019	·020	·041
20°	680	441	27·3	2·91	0·90	·019	·014	·028

For a very long time no one knew that spirits of salt and spirits of hartshorn were solutions of gases. It came to be found out in this wise. The celebrated Henry Cavendish, when experimenting on hydrogen, attempted to make this gas by acting on spirits of salt with copper. He obtained a gas which seemed to disappear as soon as it came in contact with water. Priestley repeated the experiment, and ascertained that the copper played no part whatever in the phenomenon, and that a gas might be obtained readily by heating the spirits of salt alone in a flask, and catching the gas over mercury, as in Fig. 1. The gas he obtained he called marine acid air; we now name it hydrochloric acid. It seemed to Priestley that spirits of salt was nothing more nor less than a solution of this gas in water, and the experiment immediately suggested a new line of inquiry—Might there not be many liquids deriving their peculiar properties from some gas held in solution in this manner? Following out this idea, in one of his experiments he took spirits of hartshorn, heated it, and arranged matters so that if any gas came off it would be caught over mercury. His expectations were realised, and he obtained a gas which he named alkaline air; we now call it ammonia.

It was not, however, all plain sailing. Attempting to get a gas from oil of vitriol (sulphuric acid), he heated that substance as usual, but to no effect, and, finally giving up the attempt, removed the candles he was heating the oil of vitriol with before he disconnected the apparatus with the vessel of quicksilver. Some of the mercury got

* 32° Fahrenheit. But among scientific men, Fahrenheit's scale is used in no other country except England, Russia, and the United States; it is almost universally abandoned in favour of the Centigrade.

into the boiling-hot vitriol; there was a smash of glass, and a portion of the hot vitriol was projected on to his hand, scalding him terribly; but in the midst of this disaster he had made a discovery, for the air was filled with a suffocating odour of burning brimstone, probably due to some new gas. Priestley, nothing daunted, and all bandaged up, proceeded the very next day to ascertain its cause. He put a little mercury into oil of vitriol, heated it, and caught over mercury a copious supply of a new gas, then christened vitriolic-acid air, now known as sulphurous anhydride. Columbus, in searching for India, found America; Priestley, in looking for a gas from sulphuric acid, obtained this sulphurous anhydride. Such discoveries have been called pieces of luck; it is, however, luck procured by indomitable industry and perseverance.

Sulphurous anhydride is very soluble in water, standing next in order to hydrochloric acid. It is produced when one burns brimstone, the suffocating smell being due to it, and it is quite irrespirable. At a low temperature (17·8° C.)—not so cold, though, as some of the Arctic winters—it is condensed into a colourless liquid, just as steam at a very much higher temperature is condensed into water. It soon takes the colour out of a piece of paper dyed blue with litmus, and because of this property it is used largely for bleaching, especially for bleaching woollen goods.

In so simple a manner did Priestley discover these three gases; and a word here about the man and his method of working will be instructive. He was born at Fieldhead, not far from Leeds, in the year 1733, and in after years he commenced at the latter place his chemical researches. His first experiments of this kind were on carbonic acid—a substance generated in large quantity in the vats of a neighbouring brewery;* and to this place he went for his supplies of it. Untrained in chemical operations, he had, for lack of money, to make his own apparatus, and one can well imagine what crude devices he would attempt, and what difficulty, as a reading man, he would have in putting some of them into practice. His methods in his own hands were, notwithstanding many drawbacks, remarkably successful; and one of his pieces of apparatus, the pneumatic trough, is now indispensable on the lecture-table. Let us explain it. The reader knows that the atmosphere has weight, and that in virtue of it water is pressed 32 feet up a suction pump, and mercury 29 inches up a barometer tube.† If you sink a tumbler in a basin of water, and then, inverting it, lift it bottom upwards until the mouth of the tumbler is nearly at the same level as the water in the basin, this same atmospheric pressure keeps the water in the tumbler above the level of the water C in the basin (Fig. 2).

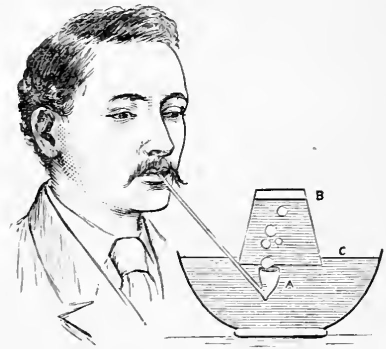


Fig. 2.—Experiment illustrating the Use of the Pneumatic Trough.

One might now place any light substance—as, for example, a piece of cork—under the tumbler at A, and it would at once rise to the level B. In a similar manner, putting the bowl of a pipe at A, and blowing down the stem, bubbles of breath rise in the glass vessel and soon fill it. This illustrates all we at present want to know: Priestley's method of caging gases in a manner that would effectually admit of their inspection. The gases were in many cases conveyed from the generating apparatus, just as the breath from the mouth in our illustration, to a vessel filled with liquid, which was gradually displaced, and thus supplies of gas were inclosed in a transparent envelope. When we employ the pneumatic trough for gases that are soluble in water, we have to use mercury instead of water, otherwise the gas which we are attempting to catch will mysteriously disappear. In such cases a small trough is employed, as illustrated in Fig. 1.

Priestley's acknowledged ignorance of the chemical methods then in use, of the mysteries surrounding matrasses, ox-bladders, and the like apparatus, compelled him to devise for himself, and the pneumatic trough is perhaps the handiest outcome of his ingenuity. After making some very original experiments with carbonic acid, forestalling the manufacturers of aërated waters, he turned his attention to inflammable air, or hydrogen,‡ concerning which he ascertained what then appeared some very strange things. Hydrogen seems to have been discovered by Paracelsus in the sixteenth century, but its properties were not exactly studied until the eighteenth century was getting far advanced. This

* Vol I., p. 52. † Vol I., p 105. ‡ Vol. I., p. 282.

is one of the experiments that Priestley made with it:—Within a jar, say A (Fig. 3), full of hydrogen, a vessel *c* containing minium rested on the surface of the water in a trough. Minium is an oxide of lead: that is, a body formed of the metal lead and the gas oxygen, just as rust is formed of iron and oxygen. It will be seen, then, that the minium was thoroughly surrounded by an atmosphere of hydrogen; and now Priestley, by means of a burning-lens B, converged the rays of the sun on to the minium, with what appeared to him a very strange result. The hydrogen gradually disappeared, the minium was turned into bright lead, and the water rose in the jar to the level *c'*, to supply the place of the vanished hydrogen. Where had the hydrogen gone to?

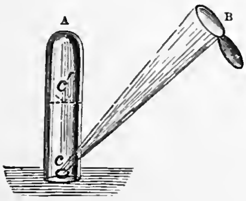


Fig. 3.—Illustrating one of Priestley's Experiments with Hydrogen.

It would be out of place here to confuse the reader with the various hypotheses held by the chemists of the time; we shall therefore tell simply what we now know to have happened in this experiment.

Water is composed of hydrogen and oxygen (p. 65). When the minium was heated by means of the lens, the oxygen in it combined with the hydrogen surrounding it to form little drops of water. The minium was robbed of its oxygen and reduced—to use a word often employed in chemistry—to metallic lead, an action which we might express by means of an equation thus:—

$$\overbrace{\text{Oxygen and lead}}^{\text{Minium.}} + \text{Hydrogen} = \overbrace{\text{Oxygen and hydrogen}}^{\text{Water.}} + \text{Lead};$$

which means that the oxygen was wrested, as it were, from the lead to combine with the hydrogen and form water.

The heating power of a powerful lens which Priestley employed in this experiment was turned to good use in making another discovery, perhaps his greatest. It was on the 1st of August, 1774, that he took some red precipitate, and arranged matters so that he could heat it strongly with the sun's rays whilst it was over mercury. Thus, let C (Fig. 4) represent a basin of mercury, having resting in it, mouth downwards, a jar A B quite filled with mercury, and with some red precipitate at the top end B. The rays of the sun were converged on to the red powder at B. The powder began to darken, and soon the mercury within the tube commenced to lower, as if some invisible gas were being prepared in the higher portions of it. And this was really the case, for by the heat of the sun Priestley had managed to break up the red precipitate into mercury and oxygen. The mercury thus procured ran imperceptibly into the other mercury of the trough, but the oxygen remained as a transparent colourless gas. This new gas Priestley found was a remarkable supporter of combustion, for a candle that he put into it burned with extraordinary vigour; he found likewise that this new gas was not readily absorbed by water.

Fig. 4.—Illustrating Priestley's Discovery of Oxygen.

Now all this was the preliminary work by means of which a grand problem—the constitution of the atmosphere—was solved. No one knew then that the air they breathed was a mixture of oxygen and nitrogen; they knew only for certain that the atmosphere supported animal life, had weight, and in moving with great speed constituted the hurricane. Its invisibility was a great drawback to its investigation, and the methods for successfully making researches on it had yet to be devised. A lively conception of the difficulties standing in the way of inquirers who sought to learn something about it may be realised by thinking for a moment of its qualities. We cannot feel or see it, nor can we taste or smell it; and the senses the chemist so largely employs seem to be quite unavailable for its investigation. If one draws a switch smartly through the air, a sense of resistance is experienced, and a whistling noise may be heard, but from this

we are able only to infer its existence. The question arises, What is it made of? It was in attempting to answer this question that the scientific men of the time became aware that they were surrounded by an oppressive darkness—a darkness that could be felt—an Arctic night; and in seeking for light they were tripped up at every turn for want of means and by the previously made and erroneous guesses—guesses which had lived so long as to come to be regarded as truths.

But not to Priestley alone is due the honour of having lightened our darkness with regard to the composition of the atmosphere. He shares it with another worker of another country, Carl Scheele, a Swedish apothecary. And before examining the goal at which they both arrived, we shall derive some instruction by travelling over the route taken by the Swedish apothecary.

At the time of which we speak, Scheele dwelt at Gefle, on the cold shores of the Gulf of Bothnia, and it was in trying to make out the nature of fire that he learnt some interesting facts about the atmosphere.

He was no novice in the art of investigation, and accordingly he proceeded with his work in a business-like manner. In effect he said to himself, "The air I breathe has certain qualities, and if I find a gas with qualities differing ever so slightly from these, I may conclude it is not common air." These are his very words:—

"(1) Fire burns for a certain time in a given quantity of air. (2) If the fire does not yield during combustion a gas similar to air, after the spontaneous extinction of the fire, air is diminished between a third and a fourth of its bulk.* (3) It is insoluble in water. (4) All kinds of animals live but a certain time in a given quantity of confined air. (5) Seeds—as, for instance, peas—will strike roots, and grow to a certain height in a given quantity of equally confined air by the addition of some water and moderate heat.

"Hence, if a gas be exhibited similar in all external appearances to air, but which, upon examination, wants the enumerated qualities (should even only one be wanting), I should think myself convinced that it is not common air."

Thus he thought, and as he worked he found many gases which wanted these qualities and had others instead of them. The gas which he named stinking sulphureous air, now called sulphuretted hydrogen, had several properties plainly not belonging to common air. Although transparent and colourless, it was obviously very soluble in water, and had a smell as of rotten eggs; it, moreover, formed a yellow substance when passed into a solution of the metal arsenic. The fact that one may obtain coloured bodies by passing this gas into solutions of other metals makes it now a very valuable substance to the chemist. If we had a solution (B) containing the following dissolved metals —lead, copper, bismuth, cadmium, mercury, tin, antimony, gold, and platinum—upon adding a little spirits of salt to it, and then passing sulphuretted hydrogen into the solution, all these metals would be thrown down, precipitated, as bodies called sulphides.

* The exact fraction is one-fifth.

More instructive still would it be to have each metal dissolved by itself, and then to pass the gas into each solution separately. We should obtain black substances, or precipitates, in the solutions of mercury, lead, bismuth, copper, gold, and platinum, yellow precipitates in the solutions of cadmium and arsenic, and an orange-coloured precipitate in the antimony solution. The colour of the precipitate in the tin solution would be dark brown or yellow, according to this metal's chemical state. Some metals are not precipitated from a spirits-of-salt solution, as, *e.g.*, iron, zinc, manganese, nickel, and cobalt, and may therefore be readily separated from those which are precipitated. Because of this property, the gas is of the greatest importance in analysis. The gas is evolved from volcanoes, and where produced deep in the earth may be dissolved to some extent by the water, and thus give rise to springs of water of peculiar odour and medicinal power, as in the case of the Harrogate waters.

To prepare the gas—Into the flask A, with a cork and delivery-tube C, place some pieces of sulphide of iron, and now add to it dilute oil of vitriol. The gas will come off abundantly, and may be passed into various solutions of the metals to test the property of precipitate-making which we have described.

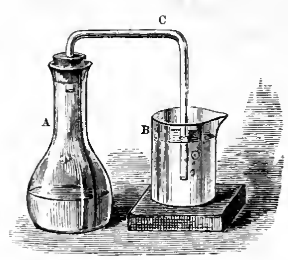


Fig. 5.—Illustrating the Preparation of Sulphuretted Hydrogen.

This discovery of sulphuretted hydrogen was perhaps one of the most important that Scheele made. Let us now inquire with what kind of tools he worked. The accompanying engraving (Fig. 6) of the page of illustrations in his famous treatise, will give us correct ideas in this

matter. His gases he caught in ox-bladders, as represented in *Figs. 3* and *4*, and in *Fig. 3* we see one of them tied to the neck of a retort to catch the gas which is being generated in that vessel. We have already spoken of the combination of oxygen and hydrogen, and *Fig. 1* illustrates an experiment in which hydrogen is made to combine with the oxygen of the air. The bottle A contains the materials from which the hydrogen is rising, say zinc and dilute oil of vitriol, and into its cork a tube is fitted, from which the hydrogen issues and is in volume of the inclosed gases is observed, and after burning a little while the candle goes out. The burning of a candle has often been compared to the life of an organised being, because the latter similarly requires oxygen, which it replaces by carbonic acid, and when it has no longer a supply of oxygen it dies. This analogy is borne out by another experiment, which shows that "all kinds of animals live but a certain time in a given quantity of confined air," and it is probably one of the earliest of the kind made. Turn to *Fig. 5.*

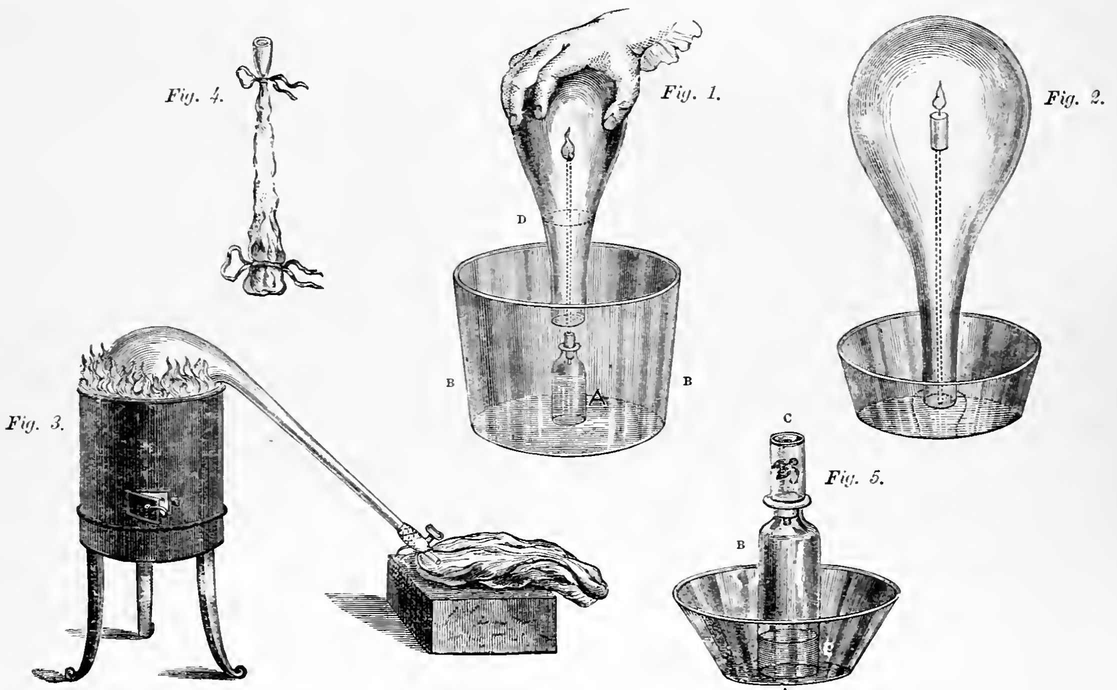


Fig. 6.—Showing the Apparatus used by Scheele and figured in his Treatise, "Chemical Observations and Experiments on Air and Fire."

ignited. The vessel B B contains water. When, therefore, a flask is brought over the flame, so that the latter may burn in the centre of the flask, all the oxygen within it is soon consumed, and fresh access of air being prevented by the water in B B stopping up the mouth of the flask, the liquid rises in the flask as the oxygen disappears. In the experiment figured, the water rose to D; the light then went out for want of a further supply of oxygen, and the hydrogen still issuing from the tube, the water gradually receded again. *Fig. 2* illustrates an experiment wherein a candle was made to burn in a limited quantity of air. Now, as the oxygen used up in an experiment of this kind takes about the same room as the carbonic acid produced in its stead, scarcely any alteration

The large basin contains lime-water, which, as the reader is aware, readily absorbs carbonic acid to form chalk.* The bottle B has a hole bored in its bottom A, and into the neck a cork is tightly fitted with a glass tube passing through it. Around the cork is laid a ring of pitch. Having now put a bee into an open glass along with some honey on a paper, this is set down on the pitch in an inverted position. B and C now form as it were one vessel, the upper portion C communicating with the lower B by means of the glass tube passing through the cork, and the only opening A is in contact with the lime-water. This, then, will be the order of events. The insect will live in the vessel C as long as there is oxygen to

* Vol. I., p. 53.

support it, and all the carbonic acid produced by its respiration will be absorbed by the lime-water. The latter will be forced up into B by the external atmospheric pressure to supply the place of the absorbed carbonic acid, and will furnish a rough measure of the oxygen originally contained in the air. In one of Scheele's experiments the lime-water rose to E in seven days, and then the bee was dead.

With such instruments and by such ways, differing from modern methods only in degree of refinement, Scheele arrived at the conviction that common air is a mixture of two gases: that one of these enables a candle to burn, an insect or higher organism to live; and that the other, quite differently, if alone, puts out a candle or destroys a life. The life-supporting constituent is now called oxygen; the gas which will not support life is called on that account in France azote, in England we name it nitrogen. As the outcome of the labours of Priestley and of Scheele, we now know that every five pints of that ocean of air at the bottom of which we live consists very nearly of four pints of the nitrogen and one pint of the oxygen. Although in the race to arrive at this conclusion Priestley was somewhat ahead of his Swedish brother investigator, he does not fail, in his published works, to honourably share the credit. We may, in fact, liken them to two travellers of different nations, who by diverse routes have arrived at the same wished-for goal, and credit is equally due to both, although in point of time one may have been a little before the other. They were both great workers, and in their investigations exemplify well Burke's observation* that, "it has been the glory of the great masters in all arts to confront and to overcome, and when they had overcome the first difficulty to turn it into an instrument for new conquests over new difficulties; thus to enable them to extend the empire of their science, and even to push forward beyond the reach of their original thoughts the landmarks of the human understanding itself."

We have learnt, then, thus far, that one of the most important properties of gases is their solubility, a property which for long prevented the discovery of ammonia and hydrochloric-acid gases; that the extent to which any gas dissolves varies with the temperature, being less at a high and greater at a low temperature. We have yet one more fact to think over, which will be grasped by our attempting to answer the question: Why does soda-water give off bubbles of gas when uncorked?

The quantity of gas dissolved by a liquid is regulated by the external pressure to which it is subjected as well as by the temperature. The law which it observes, generally known as the law of Henry and Dalton, is a very simple one. Suppose, for example, that we found one pint of water dissolved fourteen grains of carbonic acid at the ordinary temperature and pressure, then, keeping the temperature the same, we should find that with a double pressure $2 \times 14 = 28$ grains of the gas would be dissolved, and with thrice the pressure $3 \times 14 = 42$ grains would disappear. Utilising this fact, the manufacturers of aërated waters impregnate their waters with gas at comparatively high pressures. Consequently, when a soda-water bottle is uncorked, the liquid in it is exposed to a much lower pressure than that at which it was charged with gas; it therefore effervesces, and gives off a quantity of gas all above that which it dissolves at the ordinary atmospheric pressure. Natural aërated waters abound in many parts of Germany. In the electorate of Hesse-Darmstadt and the Eifel such springs are found in great numbers. Deep down in the earth the carbonic acid is probably produced by some process of vegetable decay, and the water, bubbling up, comes in contact with the gas, dissolves some, then makes its appearance at the surface as a sparkling fountain.

* "Reflections on the Revolution in France," p. 200.

WHAT IS "WORK"?

By William Dundas Scott-Moncrieff, Civil Engineer.

In a previous paper† it has been explained that *power* is that condition of energy which is capable of being converted into work. The principal natural forces which were then alluded to were heat and the force of gravity. An illustration was given of the manner in which the heat of the sun, acting upon the great reservoirs of water in the ocean, performs the *work* of raising the clouds which are afterwards stored as great accumulations of *power* or potential energy in upland lakes and

† "Science for All," Vol. II., p. 97.

rivers. Although the word *work* is really applicable to this process, inasmuch as it is one in which one form of force or energy is converted into another, in scientific language the expression is generally employed to convey the meaning of *useful* work, or energy acting through some medium arranged by human ingenuity or intelligence. Of all natural forces, that which lies nearest to our hands is the force of gravity, and the one which has assumed a place of next importance, in our own day perhaps the place of greatest importance, is heat. It is chiefly to these two forces that we will still confine our attention.

James Watt, when he was trying to discover a measure of power by which to dispose of his steam-engines, was among the first to fix upon a *unit*, or standard of measurement by which all kinds of work could be calculated and compared the one with the other, and this standard has since become universal. As it was of great importance that the measurement should be of a kind to recommend itself, from its simplicity, to every one interested, James Watt first fixed upon the power or capacity for work of a horse. Although this varied according to circumstances, and was therefore far from a scientific measurement in itself, it was made to represent a fixed natural standard, and in this way, after all, only gave a popular name to a really scientific *unit* of measurement. Experiments were undertaken to discover what work an average horse was able to perform, and this was then calculated in the form of so many pounds' weight raised a certain height in a given time. It really does not matter then how great or how little the work is that a horse can do, or how greatly the best horses of our own day excel those of the last century; the standard of work has been fixed and remains unaffected by any such changes. James Watt estimated that the work of a horse, or, as he named it, one horse-power, was the equivalent of the force necessary to raise 33,000 pounds avoirdupois one foot high in one minute. This unit varies according to the attractive force of the earth, which in some parts is greater than in others, but the variation is so slight that for all practical purposes the definition is quite sufficient, and a more specific standard, such as referring the measurement to some one spot, has never been resorted to. Now in this standard of measurement the reader will notice that there are three elements, or factors, namely, weight, or the amount of downward attraction exerted by the earth; height, or the distance through which that attraction has been resisted; and time, or the period during which the moving energy of resistance has been continued. It becomes quite clear then that the amount of work must vary with any change in these conditions. If the weight is doubled and lifted through the same distance in the same time, the work done is doubled; or if the height is doubled, so is the work; or if the same lifting force is exerted during the same time at double the speed, the height will be doubled and the work as well. In foreign countries, where the measurement of distance differs from the English foot, and of weight from the English pound, the unit of work of course varies in a corresponding degree, but in most cases closely approaches the original standard. In France, for instance, the British unit is greater than the French by the fraction of little more than one-thousandth part.

In the paper upon "Power," it was explained that the word was wrongly applied in the expression "horse-power" during the early days of the steam-engine, because the source of the power lay in the boiler, and the variations in this essential element were omitted from the calculation. The reasons for adopting so imperfect a standard are to be discovered in the absence of any instrument which was capable of measuring the actual mean pressure of steam in the cylinder of a steam-engine, and for lack of a better measurement the area of the piston and its velocity or length of stroke were multiplied by a constant number representing the pressure.

From the earliest days of the application of steam, but more especially after its introduction as a prime mover for propelling ships, our Admiralty have been very extensive buyers of steam-engines, and so they fixed upon a standard of their own for the nominal horse-power of engines, and this became afterwards a common measurement among steam-ship owners. This unit was calculated by multiplying the area of the cylinder by the mean velocity of the piston in feet per minute, by what now seems to engineers to be an arbitrary constant number 7, and dividing the product by 33,000, or the number of foot-pounds in one horse-power. If, for instance, the area of a piston were 500 square inches and its mean velocity per minute were 200 feet, then multiplying these together and the product by 7, and then dividing by 33,000, it would give us about twenty-one horse-power, the standard by which the Admiralty would have bought or sold the engine. This as a measurement of power is illusory, because the power or capacity for work of the boiler, which varies in different engines, is fixed by the constant number 7. So that if this were

doubled in practice, by doubling the steam pressure, the same engine would do twice the amount of work, and the estimate of twenty-one horse-power would be wrong by 100 per cent.

Let us see how this old standard of so-called power has been greatly given up and the more reliable basis of actual *work* adopted in its stead. The work of a horse being taken at 33,000 lbs. raised one foot high in one minute gives us the horse-power unit. and this divided by 33,000 gives the foot-pound unit or the work necessary to raise one pound one foot high in one minute. Now, on looking at Fig. 1, the standard work of a horse may either be illustrated by a weight of 33,000 lbs. passing from A to B in one minute, or by a weight of 1,000 lbs. passing 33 times against the downward attraction of the earth through the distance from A to B. Just in the same way, then, if we take the cylinder of a steam-engine, and suppose the area of the piston to be 100 square inches, and the pressure of the steam 10 lbs. upon each inch during each stroke, then the total capacity for work will be equal to that of a weight of 1,000 lbs. multiplied by the distance travelled in one minute, which (if we suppose the stroke of the piston to be 1 foot and the number of strokes 33 in one minute) will be 33,000 foot-pounds or one horse-power. Here, then, we have a measurement of work which includes the essential element of power stored up in the boiler as represented by the pressure of steam in the cylinder, and it only remained to discover some means by which this could be accurately ascertained in every case. When steam is admitted into the cylinder of a steam-engine it may either continue to follow the piston to the end of the stroke in direct communication with the boiler, or this communication may be cut off before the piston has reached the end of the stroke, and afterwards the steam may urge it forward by its own power of expansion. In a fluid like water the connection between the source of the power and the point at which it is being converted into work, must be continuous, because any interruption would make a gap in which there was no water—and therefore no power and no work. But when steam or any other elastic fluid is used, such gaps are impossible, and as long as there is enough heat in the steam to keep up the expansive force or elasticity, so long will there be a capacity for work upon every surface of the vessel confining it. In the interior of a steam cylinder the surface that becomes the medium for converting the expansive power of the steam into useful work, is that of the piston on the side which is in contact with the steam, and as this moves along it conveys away the power of the steam in the form of work. So long as the steam remains hot enough to be elastic it continues to do work, and so long as it continues to work it loses heat, and therefore elasticity, in exchange for the work done. It is quite clear then that if steam is allowed to follow a piston to the end of its stroke in direct communication with the boiler, and then to escape into the atmosphere, there will be a total loss of the working capacity of the residual steam; but if this lost steam is passed into a second cylinder and made to do work there, the waste will be greatly saved. In many engines it is inconvenient to have two cylinders, and so the same object is obtained by making one cylinder double the length, and cutting off the admission of the steam from the boiler at half the stroke, so that what would otherwise be escaping waste steam does useful work in expanding against the piston during the second half of the stroke. Supposing then that the work done by the full pressure of the steam in direct communication with the boiler in moving from A to B (Fig. 2) is represented by the number 4, and that the steam being cut off when the piston reaches B the rest of the work

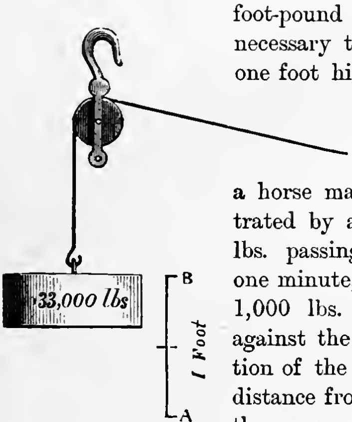


Fig. 1.—Illustrating the "Horse-power Unit."

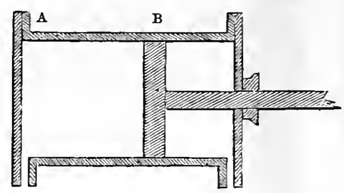


Fig 2.—Section of Cylinder.

done by its expansion is represented by the number 1, then there will be a clear gain of 25 per cent. to the steam user by making use of this steam that would otherwise have been lost.* As a matter of fact, the gain is greater than 25 per cent. in the case of steam cut off at half the stroke of the piston, as may be seen from the following

* The supposed case of doubling the length of a cylinder in order to use what would otherwise be waste steam is a popular illustration of what would be difficult to explain more technically.

table, in which the mean pressure of steam in a cylinder is shown under the portion of stroke at which steam is cut off:—

Table of Steam used Expansively.

Pressure of admission in lbs. per square inch.	Portion of Stroke at which Steam is cut off.		
	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$
10	9·6	8·4	5·9
20	19·3	16·9	11·9
30	29·0	25·4	17·9
40	38·6	33·8	23·8
50	48·3	42·3	29·8
100	96·6	84·6	59·6

James Watt had not only been the first to appreciate the great saving of power and of fuel which is illustrated by these figures, but had invented an instrument for ascertaining the mean pressure in cylinders when steam was used expansively. It was not until recent times, however, when improvements in the making of boilers led to the adoption of higher pressures and a greater expansion of the steam, that the use of the instrument was revived, and its construction improved. Although it is possible to calculate what the mean pressure of steam in a cylinder ought to be, when the initial pressure and point of cut off are known, in practice so many causes are at work to upset the theoretical result, that the instrument referred to, which is called an "Indicator" (Fig. 3), is necessary in order to ascertain what the mean pressure actually is during any particular stroke. This appliance is attached to the cylinder in such a way that the steam acts upon a small piston, thrusting it against the pressure of a spring which has been previously adjusted, and the resistance of which is known. Now it is clear that when the pressure of the steam comes directly from the boiler, it will suddenly force the piston of the indicator against the pressure of the spring until it reaches a point at which the two pressures (that of the steam on one side and the spring on the other) are balanced, and this will indicate the actual initial pressure in the engine cylinder just as clearly as any other form of gauge that could be devised. This point, by a simple mechanical arrangement, is indicated by means of a pencil, A, upon a roll of paper that is wound round a drum, D, as shown in Fig. 5. If then the highest point which has been reached by the piston of the indicator acting against the spring remained fixed during the whole stroke of the engine, and if then the drum with the roll of paper is attached to some moving part so as to revolve, the pencil, remaining fixed at one point, will trace a straight line. Referring to Fig. 3, supposing that the pencil of the indicator presses upon the roll of paper at the point of no pressure (A), then, when the pressure from the boiler passes through the valves and reaches the interior of the engine cylinder, it will suddenly force the pencil to the point of known maximum pressure (B), and so long as the pressure of the steam remains at the maximum, then, when the drum is revolved by means of the cord, the line of departure from B will remain horizontal. Supposing now the full boiler pressure acts upon the engine and the indicator piston during the whole stroke, then the diagram enclosing the parallelogram (A B C D) will represent the work done during one stroke, because it affords an exact indication of the two factors necessary to the calculation, viz., the pressure of steam and the distance travelled at that pressure, the area of the piston and the number of strokes per minute being also known. We have thus got everything necessary to make a calculation of the number of work units, either in terms of horse-power or foot-pounds. It has already been explained that using steam in the manner indicated in Fig. 3 is wasteful, because at the end of each stroke of the engine a cylinder full of steam at the full boiler pressure will be thrown into the atmosphere, and all the work it was capable of performing be for ever lost. We will now try to explain what happens when the steam is cut off before the end of the stroke, and how the effect of this is indicated by the altered shape of the diagram. The steam being admitted in the same way as in Fig. 3, the pencil of the indicator will be again forced from the point of no pressure A to the point of maximum pressure at B; and so long as this maximum pressure is maintained, the line of departure from B, as in Fig. 3, will remain horizontal. As soon, however, as the steam is cut off, by the

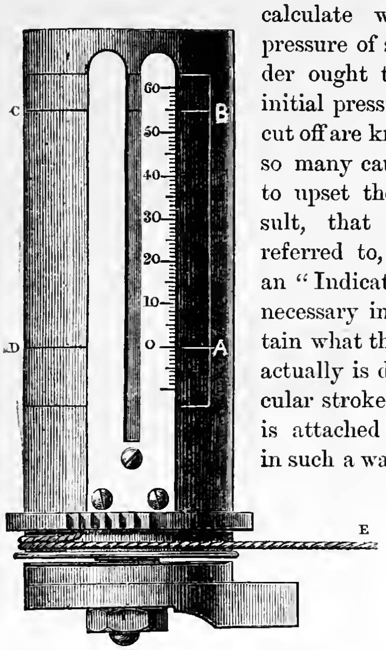


Fig. 3.—Showing how "the Indicator" tells the amount of work done in a "Stroke" at full Boiler Pressure.

action of the slide valves, say at C, Fig. 4, the work of forcing forward the piston is immediately done by the expansive force of the steam in the cylinder alone, without receiving any further supplies from the boiler. The pressure of steam, therefore, diminishes at the point C; and as the pressure of the spring behind the piston of the indicator is no longer balanced, it forces the pencil to descend in a less sudden manner than it ascended along the line A B, and thus traces a curved line from C to E, produced by the rotary movement of the drum and the downward movement of the pencil. Here again, then, we have a complete index of all that is necessary to calculate the work performed by the engine during the stroke to which the diagram refers. As the parallelogram A B C D, in Fig. 3, represents the full boiler pressure indicated by a properly adjusted pressure scale on the line A B, multiplied by the distance through which that pressure acts, as indicated by the line B C; and as these factors, along with the area of the cylinder and the number of strokes per minute, are all that is necessary to calculate the work; so in Fig. 4 we have a similar parallelogram (A B C F) up to the point C on the line B C at which the steam was cut off, the maximum pressure and the distance during which it acted being represented by the area of the figure A B C F. To this must be added the remainder of the diagram (C F D E), which indicates the mean pressure during the rest of the stroke and the distance through which it acts from F to D. In other words, the area contained by the figure A B C E D will represent the work done when the cut off takes place at that portion of the stroke represented by the letter C on the line C B; and the waste of steam at the end of the stroke,

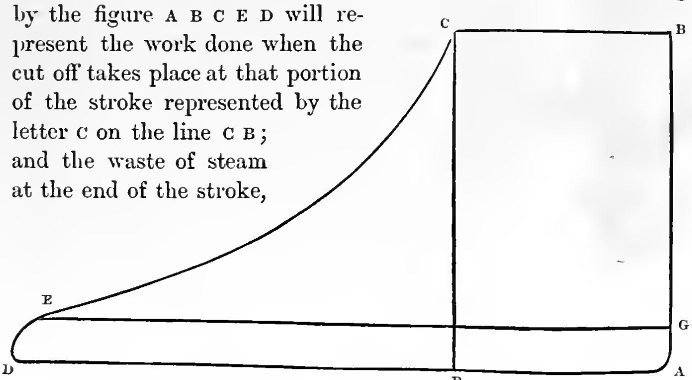


Fig. 4.—Showing Work done under Maximum and Mean Pressure.

instead of being a cylinder full at the maximum pressure indicated by the length of the line A B, will be a cylinder full at a pressure indicated by the height D E or G A, the loss of steam, thrown into the air at the end of the stroke, being indicated by the area A G E D, or the pressure A G multiplied into the distance travelled by the piston in one stroke A D.

Among instruments of measurement, there is none that holds a more important place in the every-day practice of mechanical engineers than the indicator (Fig. 5), because it is by its means alone not only that the actual horse-power, or rather horse-work, of an engine is calculated, but also because it supplies an index of every form of error, both in the adjustment of the slide-valve, and even faults in the general construction of a steam-engine itself.

We will now go on to another branch of the subject in which work is measured, not in relation to the useful efficiency of prime-movers, but in the aspect of a force in relation to other forces. At this point a peculiar interest attaches to the work-standard laid down by James Watt, because it has since been employed as a unit of measurement in the co-relations of forces, a subject which is identified with many of the most brilliant discoveries of the nineteenth century, and one which he would no doubt have adorned by his genius if he had lived. The early history of these discoveries, as often has happened in other departments of science, was made up of arguments brought forward by the advocates of two rival theories, in which the combatants, by their efforts to adduce facts and deductions in support of opposite opinions, gradually supplied the materials for arriving at the truth. True conceptions of the nature of different forces, which are now the common property of any person of intelligence who pays a shilling for a text-book and studies it, were, in the beginning of the last century, exceedingly rare, even among the most profound mathematicians, and mistaken notions retarded the investigation of their relationships. Heat was called caloric, and looked upon by most men of science as an impalpable fluid, the motions of which were studied on this assumption. When such a theory prevailed, the idea of heat being convertible into work, and work into heat, must have appeared as altogether unwarranted. Certain theories existed that vaguely led to such a conclusion, but they belonged to a period whose scientific methods of investigation had been displaced by the system of deductive reasoning from facts, and such authorities as Aristotle, or even Bacon, who had both given expression to the idea of the co-relationship of natural forces, were not looked upon as being of any weight, even at the time when the doctrine was

on the eve of its demonstration. We are here trespassing upon a subject that demands a larger share of attention than can be devoted to it in this paper; but as no account of work would be complete with-

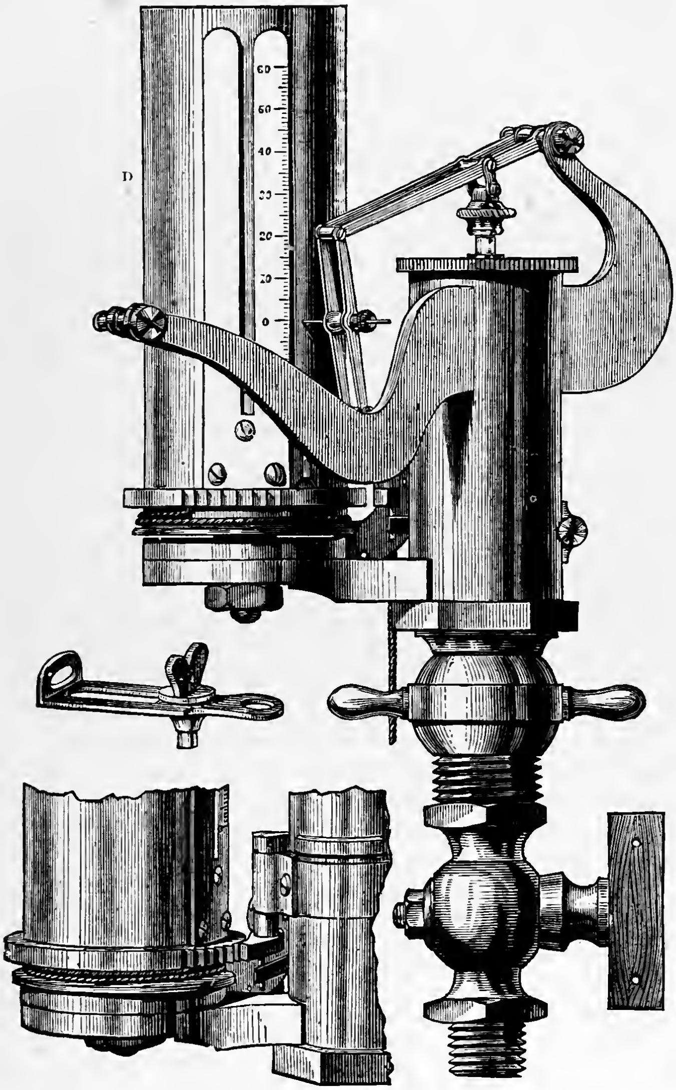


Fig. 5.—The Indicator.

out a reference to its relation with at least one force besides that of gravity—viz., heat, we will try to convey an idea of this connection in as few words as possible. The first person whose mind was thoroughly disabused of the notion that heat was a subtle imponderable fluid was Count Rumford.*

* Count Rumford, whose name was Benjamin Thompson, was driven to Europe for his loyalty during the Revolution in America. He attained distinction in Bavaria, and chose his title from the village he had left in New Hampshire.

When he was superintending the boring of cannon in Munich, he noticed that the heating, which was the consequence of the friction of the tools upon the metal, was derived from an apparently inexhaustible source, and so he very reasonably concluded, in his own words, "that anything which any insulated body, or system of bodies, can continue to furnish without limitation cannot possibly be a material substance." Such ideas about heat and work were at first the possession of the few, but soon began to be the foundations for the investigations of many. The steam-engine was beginning to be looked upon as a heat-engine, and the source of the power traced to the fuel in the furnace. Then men of science began to ponder over the relationship between heat and work. Sadi Carnot, in trying to discover *how work is produced from heat,* was labouring at one side of a calculation, that may be roughly illustrated by supposing a person to be working at the relationship between 2 and 3, and thereby suggesting to another the relationship between 3 and 2, or *how heat is produced from work.* About this time another natural force, which had been considered by many to be such another imponderable fluid as heat, was suspected to be in the same category, and this was afterwards proved to be the case by Seebeck, in the production of electromotive force from heat, the heat itself being produced, if necessary, from other forms of force which were capable of exact measurement in terms of the work-unit of foot-pounds.

Sir William Thomson applied the work of Carnot to devising a thermometric scale, based upon the relationship of work and heat; and this again opened up a new conception of the limits of temperature which had never before been thought of. Count Rumford extended his experiments upon the production of *heat from work* to the effects produced upon water by churning, and in doing so had worked in a direction that in other hands opened a new channel for a discovery of their relationship. The question remained, how much work will produce a certain amount of heat, the work-unit being taken at one pound raised one foot in one minute? The answer was given by Joule, of Manchester, who

announced to the world, in 1849, that if the unit of heat is taken to be the amount of heat necessary to raise one pound of water one degree Fahr., then the equivalent of work necessary to produce a heat unit is 772 pounds, falling through a space of one foot. Applying this to the case of a steam-engine of one-horse power, we find that if we estimate the calorific efficiency of one pound of coal at 12,000 heat-units (which is perhaps the nearest approach to the truth that has yet been made, then the work-units it contains will be 12,000 × 772 = 9,264,000 foot-pounds, whereas in the best engines this amount of fuel is capable of developing only 990,000 foot-pounds per hour. The importance of the discovery of the exact mechanical equivalent of heat in the every-day work of the mechanical engineer it is impossible to over-estimate. As it is his principal business to insure economy in the use of those stores of energy which we discover in our coal-fields, the knowledge of the exact relationship which ought to exist between heat and work is the basis upon which waste and loss is calculated. By this knowledge he has a goal, which all his efforts should be strained to reach. Nor is the margin between theory and practice so narrow that no room for improvement is possible. In a first-rate steam-engine, about eight-ninths of the capacity for work stored in the fuel is lost. This startling discovery would never have been made but for the patient experiments that led to the great announcement of Joule, which has thrown a light at the same time upon other departments of industry, in which the waste goes on in a still more outrageous proportion.

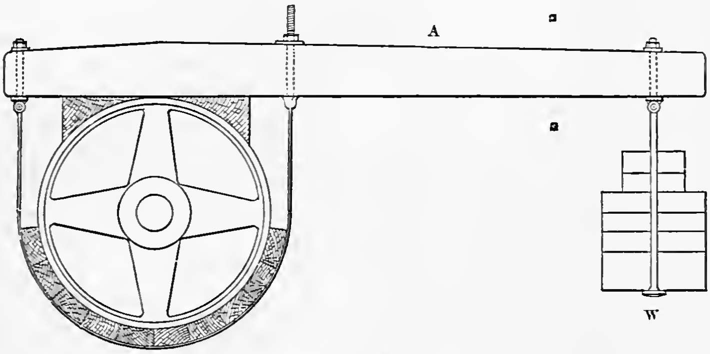


Fig. 6.—The Dynamometer.

For the purpose of estimating the total amount of work performed by such a prime-mover as a steam-engine, there is no more reliable instrument than the indicator which has already been described, but it is often of great importance to be able to ascertain what amount of work is being absorbed by friction among the moving parts of the engine itself. For this purpose a dynamometer (Fig. 6) is employed, by which the amount of work done by the prime-mover, over and above that which is required to overcome the friction of its parts, is ascertained. This is done by loading a friction-brake (A) to a known amount by weight (W), and estimating the work done in a given number of revolutions of this drum. Deducting this amount of work, then, from the total shown by the indicator, will leave a balance that represents that which is lost in overcoming the resistance inherent in the moving parts of the engine. Mr. Froud, within the last few years, has opened up a new field of inquiry by this means, which is of itself an important contribution to the science of practical dynamics.

THE HAND.

By F. Jeffrey Bell, B.A., F.Z.S., British Museum.

In treating of any part of the body, we may deal with it in one of two ways; we may speak of its uses or functions, its present powers, and its educated possibilities, that is, we may treat of it from a *physiological* point of view; or, on the contrary, we may deal with its structure, its variations, and its history, that is to say, we may deal with it *morphologically*. In the present paper we shall speak chiefly of this second aspect of our subject, and we shall at once commence what we have to say with a short description of the human hand.

Like all similar parts, this may be divided into three regions, the simplest names for which are wrist (*carpus*), palm (*metacarpus*), and digits. Of the digits, or fingers, there are five, all but one of which are provided with three joints (*phalanges*); the single exception is the thumb, in which there are

but two joints. The ordinary names for the other digits are (1) pointer or index; (2) middle finger; (3) ring finger—so called as being that on which Christian brides, at any rate, have been in the habit of wearing the marriage-ring, and whence, as the beautiful fable reports, a vein goes direct to the heart; (4) little finger (minimus). That foot of a verse which is known as the *dactyl*, and which is made up of one long and two short syllables, is so called from the Greek word for a finger. The palm also exhibits the number five, consisting as it does of five elongated and slender bones, terminating in large rounded heads, on which the first joints of the fingers can easily play (Fig. 1).

The wrist itself is short and broad, and in man is made up of eight bones arranged in two rows; on the one side it is connected with the bones of the palm, and on the other with the outer bone (*radius*) of the fore-arm, and indirectly with the inner bone (*ulna*). It will not be necessary to give all the hard names of these, but there are one or two which demand a special notice; and first of all, that which is connected with the thumb. As is well known, this digit is, in ourselves, capable of an extraordinary amount of movement, and by itself might be said to be nearly equal to all the other digits put together; thus, it is capable of movement in two distinct planes; it can move inwards over the palm, and it can also move downwards so as to be set at right angles to the palm and fingers. Such an arrangement has naturally enough excited the admiration, and at times inflamed the reason, of naturalists. The matter has been put in the clearest light by Professor Owen, and we shall do well to quote his words: "Man's perfect hand is one of his peculiar physical characters; that perfection is mainly due to the extreme differentiation of the first from the other four digits, and its concomitant power of opposing them as a perfect thumb. An opposable thumb is present in the hands of most Quadrumana [the apes, &c.], but is usually a small appendage compared with that of man." It may therefore be supposed that the bone on which this thumb plays is of a peculiar character; and so it is, for instead of having a simple rounded head, or a correspondingly simple hollow to receive a rounded head, it is saddle-shaped on the face to which the innermost bone of the palm—or that for the thumb—is attached. Occupying almost the centre of the wrist, though reaching to the palm, is a large bone, which is almost always known as the *magnum*, or great bone of the wrist; but it is curious to observe, as an example of the history of Comparative Anatomy, that in most animals this bone is of a comparatively inconsiderable size, while it may warn us against the too common error of arguing from what happens in man as to what will happen in the lower animals. Of the remaining six, one, the pea-shaped bone (*pisiform*), does not belong to quite the same series as the rest; while two are connected with the radial bone of the fore-arm, the boat-shaped (*scaphoid*) bone, and the semilunar.

These various bones are moved on one another by a number of muscles, which form the fleshy part of the hand, and these again are roused to activity by nerves, and enabled to effect their work by the supply of nourishment afforded them by blood-vessels. The muscles are arranged in two distinct sets; one the so-called *flexors*, placed on the palmar aspect, flex or bend the fingers; while others, on the opposite surface, are the *extensors*, which draw the finger-joints back again, or bend the back of the hand on to the arm. It would not be right to give here a detailed account of the distribution of these muscles, but it will perhaps be interesting to explain the anatomical relations which, in the pastime of "Sir Creswell Creswell," prevent the tips of the ring fingers from separating when the middle fingers are flexed. The tendon which goes to the back face of the ring finger gives off two tendinous bands, one for the middle, and one for the little finger; when, therefore, either of these fingers is flexed, the ring finger has its tendon held down, so that its proper action—which is, of course, to extend the ring finger, or bend it towards the back of the hand—cannot be put in use. We must not describe in any detail either the nerves or the vessels, though with regard to one of each a word must be said. And first, as to the nerve, which is not only one of those which go to the muscles, but one of those by which we *feel* the action of various influences on the skin of the hand. We all know that when we strike the elbow at a particular point, a peculiarly painful sensation is felt in the hand; this, which is due, in the first place, to that law of nervous action by which irritation of a *sensory* nerve gives rise to a feeling in the parts to which it is finally distributed, is effected by the course taken by the so-called *ulnar* nerve, which comes very near to the surface at the elbow, and then passes on to the hand, giving off some branches to muscles, and some to the skin. The vessel to which we would refer is that by which we "feel the pulse;" it belongs to that series which carries blood from the heart, or the arteries, and is distinctively known as the *radial* artery; unlike most of that series it is at the

wrist largely exposed, and so forms a convenient and ready method of testing the action of the heart, rising and falling as it does after each contraction of that organ. As to the skin, we need only point out the complete absence of hair from the palmar face, and the comparatively slight extent to which it is developed on the back of the hand; still, a few words must be said as to the nails, without our attributing to them as much importance as do the Chinese, or those Africans that colour them yellow or purple. The peculiar points about the nails of man are that they are all flat, and that they do not in any way seem to afford protection for the ends of the fingers by growing round them, as do the hoofs of the horse and cow, for example. As regards the flattening of all the nails we must, however, observe that in the orang, the chimpanzee, and the gorilla the same obtains, while in the gibbons it is only on the thumb (and on the great toe) that the nails are flat. The white part of the nail is known as the *lunula;* its appearance is probably due to the thickening of the "bed" of the nail at this point and to the less rich supply of blood-vessels, which shine through under the rest. Among other proofs of these parts being nothing more than somewhat altered parts of the skin is the fact that they are made up, like the scarf-skin itself, of flattened scales, while the younger parts, just like the younger cells of the outer skin, are more rounded and softer. The best proof of all is afforded by some of the frog family, where the skin (*epidermis*) is merely thickened at the ends of the different digits. Instances have been observed of nails growing on the stumps of amputated fingers.

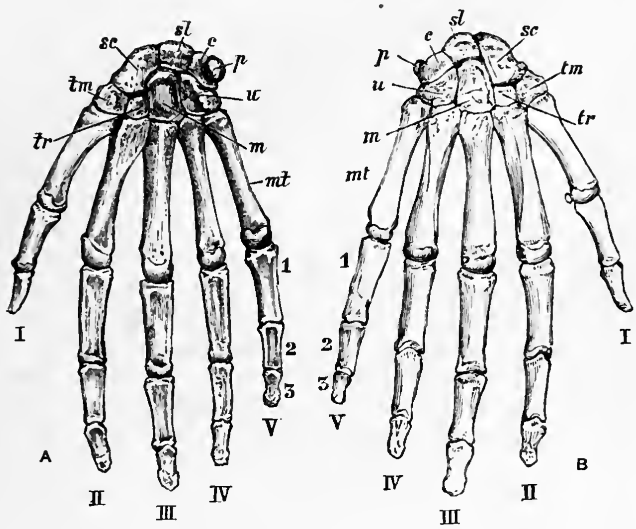


Fig. 1.—Bones of the Hand of Man. (A) palm; (B) back.

I, II, III., IV., V., indicate the Digits on Fingers; 1, 2, 3 (see Digit V in A and B) mark the Phalanges or Joints; (*m*) Magnum; (*mt*) Metacarpals; (*u*) Ulnar; (*p*) Pisiform; (*c*) Cuneiform; (*sl*) Semilunar; (*sc*) Scaphoid; (*tm*) Trapezium; (*tr*) Trapezoid.

On account of the striking difference in the powers of the hand and foot in man, as compared with monkeys, the terms *Bimana* (two-handed) and *Quadrumana* (four-handed) have been applied to them respectively; but with regard to this it must be observed that there are numerous peculiarities which distinguish the hand (Latin, *manus*) and the foot (Latin, *pes*), and that with regard to these points the foot of the ape is as truly a foot as that of man; and again, if the word *hand* is to be taken as meaning merely a seizing organ, then many monkeys might be called five-handed, for their tail is as much of use to them as their hands or feet, and the elephant might at least be credited with a very powerful hand, for its trunk is a most useful, as well as a most amusing and dangerous seizing organ. The Greeks recognised this, as is shown by their having applied their name for the hand to the trunk of this creature. The difference between man and apes was insisted upon by Blumenbach and Cuvier; but the sagacity of Linnæus, the veritable father of modern zoology, had saved him from such a course, the ill-advisedness of which must strike every one who has seen, as it has fallen to the lot of the writer to see in the Museum at Antwerp, a man, maimed of both hands, copying with exquisite precision some of the glorious masterpieces which adorn the walls of that building, in the city of Rubens. This artist—we cannot call him this cripple—held a brush between his toes, and, moreover, laid aside that brush to wipe from his brow the fated reward of his labour.

Having commenced with saying that we would deal more with the form than with the function of the hand, we might perhaps escape comment even if we said not a word as to right or left-handedness; but all functions depend sooner or later on structure, and the "common error," of which a distinguished writer on the hand has spoken, "of seeking in the mechanism the explanation of phenomena which have a deeper origin," cannot be fairly taken as applying to parts which owe all their activity to the supply of blood which they receive either directly or indirectly. The explanation to which the words just quoted referred was that "the superiority of the right arm is owing to the trunk

of the artery which supplies it passing off more directly, so as to admit of the blood being propelled more forcibly into the small vessels of that arm than the left." This explanation, indeed, has not much anatomical evidence to support it; but that which ascribes the superiority to the freer supply of the blood to that part of the brain whence messages are sent to the right hand has a strong basis in fact. The question is one which has been much discussed, and it is impossible to give all the views on it, but the ingenious explanation that those who advanced the right side first in battle would be less exposed to fatal wounds is one which it is right to mention. There is a peculiarity in some right-handed persons which is extremely curious: it is this—they always deal cards with their left hand, and that although for other purposes it is just as useless as in most men. Finally, it may be mentioned that an eminent surgeon is reported to have urged on his pupils that they should always *knock on a door with their left hand*—a forcible way of putting the fact that success in surgery will always come most largely to those who are *ambidexter*. How far right-handedness is due to nature, and how far to education, is a somewhat barren question, as it is obvious that a habit, if long enough brought about by education, will come to be brought about by heredity: that is, by nature, if the word nature have any meaning at all in this question—a question which, it should be added, has been put often enough.

Turning now to the lower animals, to learn from them some of the changes which this organ may undergo, and to understand the degree of its perfectness in man, we commence with a few words on the higher apes. It has already been pointed out that the hand of the Quadrumana differs in no essential point of structure from that of the Bimana (man)—it "possesses not only every bone, but every muscle which is found in that of man." The difference lies in the degree to which these are developed; thus, the thumb is in all cases smaller: but this of itself may be an advantage to them, as they use their hands more for climbing than for construction, and it is in those that are excellent climbers or that live always in trees—in such forms, that is, as the American spider-monkeys, the Asiatic gibbons, or the African colobus—that we find the thumb most reduced. But the hand itself is but the terminal portion of an organ—the arm, which, it is to be observed, is proportionately longer in monkeys than in man. This peculiarity is also to be noticed in children as compared with adults, although, indeed, the representations of painters often obscure it, so that much of what looks false to nature in portraits of young princes, infantas, and so on, is due to want of correct observation on this anatomical peculiarity. This length of arm seems to be inconsistent with the upright position; but we must remember that the higher apes can move along without the aid of their hands, and although, as Mr. Darwin tells us of the gibbon, they move awkwardly and much less securely than man, yet when this ape does walk upright it is reported to only touch the ground now and then, just as does a man who carries a stick without requiring the use of one.

It is a general rule in all mammals—that class of the animal kingdom to which man belongs—to have never more than two joints in the thumb, and three in all the other fingers; and this rule applies also to the corresponding parts of the lower limb—the foot: in none of them, any more than in any bird, any living reptile, or any one of the frog class (*Amphibia*), are there more than five fingers to the hand—except, of course, in cases of monstrosity, such as in six-fingered men or women. To the first rule there is but one exception, and that is found among those animals which, though living in the sea, are veritable mammals, and which, like all others of their class, are unable to breathe the air dissolved in the water, and have continually to come to the surface to respire; these are the whales. In them the hand does indeed seem to be very remarkably metamorphosed; seen from the outside, there is no indication of the presence of separated fingers, not even the slight one that could be given by the presence on it of claws or nails: it is converted into a flipper-like paddle, set close to the body. When, however, the skin and muscles are removed it is seen to possess wrist, palm, and four or five fingers, just as does man, but the joints of these fingers are not limited to two or three, and there may even be as many as twelve or thirteen phalanges in some of the digits. In those whales that develop whalebone in the place of teeth, many of the parts of the hand never become bony at all, but remain cartilaginous; the joints, too, between the different parts are not developed, and the only power that the hand has of yielding or bending is such as it can gain from the elasticity of cartilage. To show how variable the number of the phalanges is, it will be sufficient to state how they are set in the two forms of whales best known to most of us. The porpoise: this animal, which is not rarely seen even as far up the Thames as London Bridge, has

two phalanges in the thumb, eight in the next finger, and then six, three, and two; in the common dolphin there are two, ten, seven, three, and one phalanges, while in the round-headed form there are as many as fourteen joints in the index finger (Fig. 2). Of the mammal class there is yet another group which is purely aquatic, and, speaking generally, this mode of life is about their only point of similarity to the whales. Of these, the Sirenia (or mermaids), we now only know two living forms; a third form (*Rhytina stelleri*) has died out within the last century, but fortunately the figure of it was painted, and the anatomy studied a little by Steller, one of the companions of the celebrated voyager Behring. Owing, probably, to their mode of life these animals have the hand converted into a paddle, and no signs of separate fingers can be made out in the living form; but the inspection of their skeleton reveals the presence of a hand which, by the possession of five digits and the ordinary number of phalanges, agrees essentially with that of man.

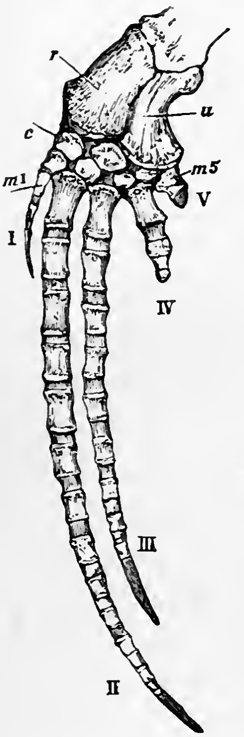


Fig. 2. — Hand of Round-Headed Dolphin.
(I—V), Digits: (*r*) Radius; (*u*) Ulna: (*c*) Carpus; (m^1, m^5,) first and fifth Metacarpal.

There is another group of mammals which, unlike most of their kind, do not walk on land, but are flying animals; these are the bats (*Chiroptera*—wing-handed animals). The accompanying figure (Fig. 3) will show better than any description the difference between the arms of these animals and the arms of the birds who are, amongst vertebrates, the flying animals *par excellence.* It is therefore necessary only to point out that the surface required to support the animal in the air, and which is formed by outgrowths of the skin itself, is chiefly provided for by the great elongation of the bones of the hand; the thumb is not included in this fold of skin, but forms a claw by which the animal may support itself on trees and bars. The metacarpals (or bones of the palm) are greatly elongated, and, as a rule, are succeeded by *two* phalanges, which are also very long and very slender. It is striking to observe that, notwithstanding the extreme length of the bat's hand, the number of phalanges should be even less than in man. The other members of the mammalia which are able to fly—the flying lemur of the Indian Archipelago, the flying squirrels, and the flying phalangers of Australia (Vol. I., p. 198)—are not aided by any modifications of the hand, nor is their flight long-continued or steady. We shall shortly refer to what obtains in birds.

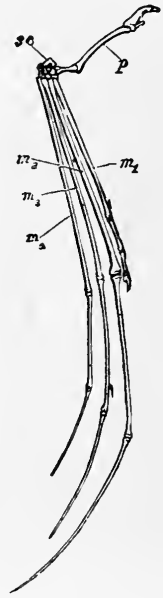


Fig. 3.—Hand of Bat.
(*p*) Pollex; (*sc*) Scaphoid: (m^1—m^4) the four Metacarpals.

As we cannot deal with all the marvellous variations in the structure of the hand which are seen in mammals, we will pass on to a group in which the reduction of the digits affords one of the easiest, as well as one of the most instructive, series of changes which can be found in the whole realm of comparative anatomy: these are the hoofed animals, or *Ungulata,* of which there are two series, markedly distinguished by many anatomical differences. For our purpose the most important is that in one the number of digits is always even, and in the other always odd; to this, however, there are two curious exceptions. To the one group belong the tapirs, rhinoceroses, and horses; to the other sheep, oxen, deer, goats, and pigs. But with regard to the tapir, that curious, old-fashioned-looking animal which is now found living only in such widely distant regions as South America and Sumatra, we have to observe that there are four toes on the hand, though only three on the foot, and that of these four toes the outer one has ceased to touch the ground. The other exception is also found in a South American form—the peccary; but the peculiarity here lies in the foot, in which there are only three, and not, as in the hand, four toes. Of all these beasts the most remarkable is the horse, in which only one digit is developed and touches the ground. The bones of this member are greatly elongated and are very strong; the wrist, or carpus, is even here made up of seven bones, the largest and broadest of which is the one that we have already heard about—the *magnum;* in the metacarpus there are two narrow bones, one on either side, which represent the second and fourth metacarpals; these flank a large and long bone—the highly-developed third

metacarpal; and this, again, is succeeded by three phalanges, the two lower of which are broadened out, and the last one most remarkably so. Owing to the length of the bones below the carpals, the

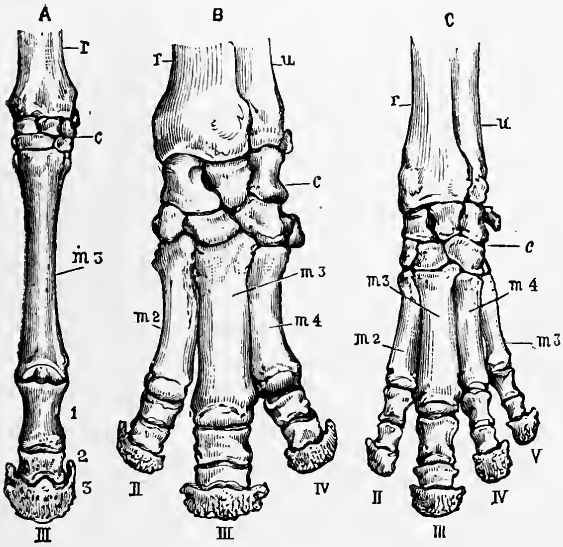


Fig. 4.—Hand of *Horse* (A), *Rhinoceros* (B), and *Tapir* (C).
(r) Radius; (c) Carpus; (u) Ulna; II., &c., mark Digits; (1, 2 3) Phalanges; (m2, m3, m4) Metacarpals.

wrist gets to be so high from the ground that it ordinarily goes by the name of the "knee" (Fig. 4).

In the rhinoceros three toes touch the ground, but the middle one is larger than those on either side; while, as we see in the above figure, the tapir still retains its fifth digit, shortened a little though it be. A still more instructive series of changes has been made out by the aid of a study of some fossil forms which were, without doubt, closer

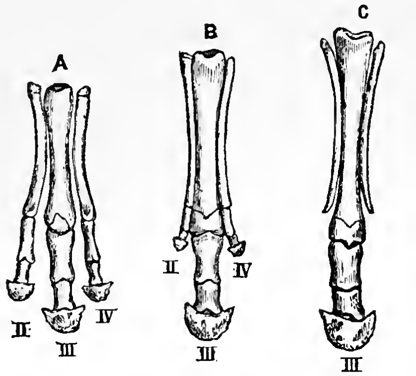


Fig. 5.—Foot of *Anchitherium* (A), *Hipparion* (B), and *Horse* (C).

allies to the horse than are either the tapir or the rhinoceros. These are known as *Hipparion* and *Anchitherium*. When we compare—as by the aid of the subjoined figure (Fig. 5) we are enabled to do—the hands of these three forms, we observe that the toes get shorter and shorter, until at last the digits cease to be developed. Nor is this all the story; to explain which we must say that the later periods of the history of our earth are, or may be, divided into five: Early Eocene, Later Eocene, Miocene, Pleistocene, and Existing [Frontispiece, Vol. I.]. Now the modern horse is only known in the last two of these periods, *Hipparion* in the third and fourth, and *Anchitherium* in the second and third. A still earlier form, to which the ever illustrious Cuvier gave the name of *Palæotherium*, has not been found in any layers which belong to a later period than the Later Eocene; in this form, again, there were only three digits. In addition to this, we have to observe that the rhinoceros has been found in Indian deposits of the Miocene epoch, and the tapir in the deposits of the same period near Auvergne. We see, then, a series of changing forms going hand in hand with changes in the earth's surface, while the scarcity at the present day of the almost unchanged tapir and rhinoceros, and their greatly restricted range, are full of significance as to the necessity of adapting oneself to circumstances, when one is desirous of continuing to exist.

Had we space, we might enlarge at greater length on this most interesting and instructive subject, and might draw many examples from the even-toed forms, but we must content ourselves with attracting attention as briefly as possible to the studies of a Russian anatomist, who illustrated the reality of the great republic of Science by drawing his examples from specimens in the British Museum. This gentleman has, by the study of fossil forms, shown that in some of these the median metacarpals did not seize on the outer carpal bones, when the digits with which these bones articulated dropped away; and that *such forms have disappeared.* In others, again, such as the deer or the ox, the carpal bones became connected with the remaining and median metacarpals, so that in them, just as in the horse, the number of bones in the wrist is not very greatly reduced, and "a better and more complete support for the body" is thereby gained; *such forms have not disappeared.* To these two modes Dr. Kowalewsky has given the appropriate names of *adaptive* and *inadaptive* modifications.

It is impossible to speak of the other mammals; and we must now begin to draw our notes to an end by giving a rapid sketch of the changes in arrangement which convert the typical five-fingered hand into part of a wing. In very nearly all birds there are three digits, one of which is the thumb,

which does not here disappear so readily, as it were, as it does in so many quadrupeds. In many birds this thumb retains a claw, in some the index finger does so also, but in no known case is there a claw on the third (*median*) digit; the thumb is connected with a short metacarpal; the other two bones

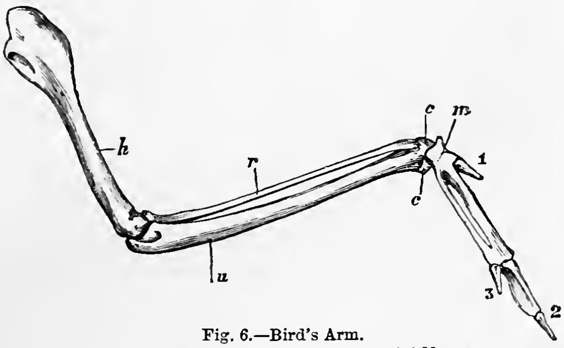


Fig. 6.—Bird's Arm.
(*h*) Humerus; (*r*) Radius; (*u*) Ulna; (*c*) Carpus; (*m*) Metacarpus; (1, 2, 3) Digits.

of the palm are very largely fused into one bony mass; and the bones of the wrist are reduced to two (Fig. 6).

We come now to the final question—What is the meaning of these relations common to all hands? why is the number five so constant and so characteristic, and yet why is it at times so extraordinarily modified? To answer these questions would be to write a chapter in the History of Creation; but at the same time, there are a few facts which cannot be passed over. When we examine the arm and hand of one of the simplest of the five-fingered forms—a representation of which is here given (Fig. 7, A)—we find (1) a single bone, (2) two bones, (3) a set of ten bones, (4) a set of five bones, and (5) five digits with a number of bones in each. Along this we can draw one straight line, and on one side of this four other lines, passing out like rays from a central stem. It is clear that the rays of the other side have been lost if the hand of the Amphibian is really based on a "type" of such a kind at all; whether it is so or not, it is curious to observe that such a "type" does exist in a remarkable form which has lately been found in the rivers of Australia, and of which an instructive figure is given (Fig. 7, B).

We have now traced the hand of man through various, though through few series, and have seen how under varying circumstances its structure becomes altered; yet, with all these changes we have seen striking points of similarity in all, and we have lastly been able to see a possible origin for all these forms; so that we have had illustrated to us the two chief modes by which peculiarities of structure are brought about —"the influence of heredity," by which the "typical form" is preserved, and the influence of surrounding circumstances and of changed habits of life, which have effected the most wonderful changes in arrangement within a comparatively restricted area of structure.

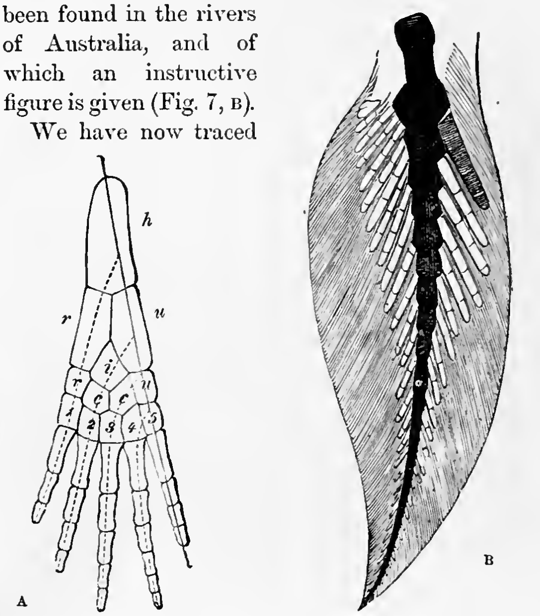


Fig. 7.—Diagram of Fore-limb of (A) *Amphibian*; (B) of *Ceratodus*.
A.—(*r*) Radius; (*h*) Humerus; (*u*) Ulna.

HOW GLACIERS MOVE.

By W. F. Barrett, F.R.S.E., M.R.I.A.,
Professor of Physics in the Royal College of Science for Ireland.

In a former article (p. 181, Vol. II.) we have seen what a glacier is, and how, in the course of its slow journey from the region of perpetual snow, it exhibited phenomena of wonderful interest. But of all these phenomena the mere fact of its motion is not the least remarkable. We will now inquire how it is that a seemingly solid, hard, brittle river of ice passes from the upper Alpine regions down into the valleys among the vineyards, or in the Arctic regions to the sea, accommodating itself to all the

inequalities of the ground, and in nearly every respect behaving just as if it were a river of water.

That the glacier possessed some kind of vital agency used to be a current belief among the peasantry of the Alpine valleys, a belief that arose from the fact that foreign bodies, such as large stones, dropped into a crevasse, were found after weeks or months rejected by the glacier. This apparent rejection of bodies was proved by M. Agassiz, who placed plugs of wood at various depths in a hole dug for the purpose in a glacier. These were successively discharged, according to their situation in the hole. The rejection of foreign substances by the glacier is, however, only apparent; they remain in their original position, but the surface ice of a glacier being in a constant state of liquefaction, the ice is gradually melted to the level of these bodies, and they then become visible on the surface. Many other illustrations of this glacial "ejection" might be given; one or two examples will show the use that may also be made of them in calculating the rate of motion of a glacier.

An Alpine guide, named Contet, found, in 1846, fragments of a knapsack which had been lost ten years previously in a deep crevasse; the contents were undestroyed and formed a certain means of recognition. It was found on the surface of the glacier 4,300 feet lower down than the spot where it had been lost, giving an annual movement of 430 feet. The space travelled over includes a spot where the ice is dashed over a rapid 1,000 feet high. Again, in the highest part of a glacier near Chamouni, a sudden and noiseless descent of snow carried over a precipice, and buried, the leaders of a party ascending Mont Blanc. This was in 1820, and happened only 1,000 feet from the summit of Mont Blanc—at a height, that is, of 14,700 feet. In 1861, some guides, while crossing the lower part of this glacier, found bones, skulls, knapsacks, and other traces of this party. This was at a height of only 4,400 feet; the descent, therefore, in forty-one years was 10,300 feet, equal to nearly 500 feet a year.

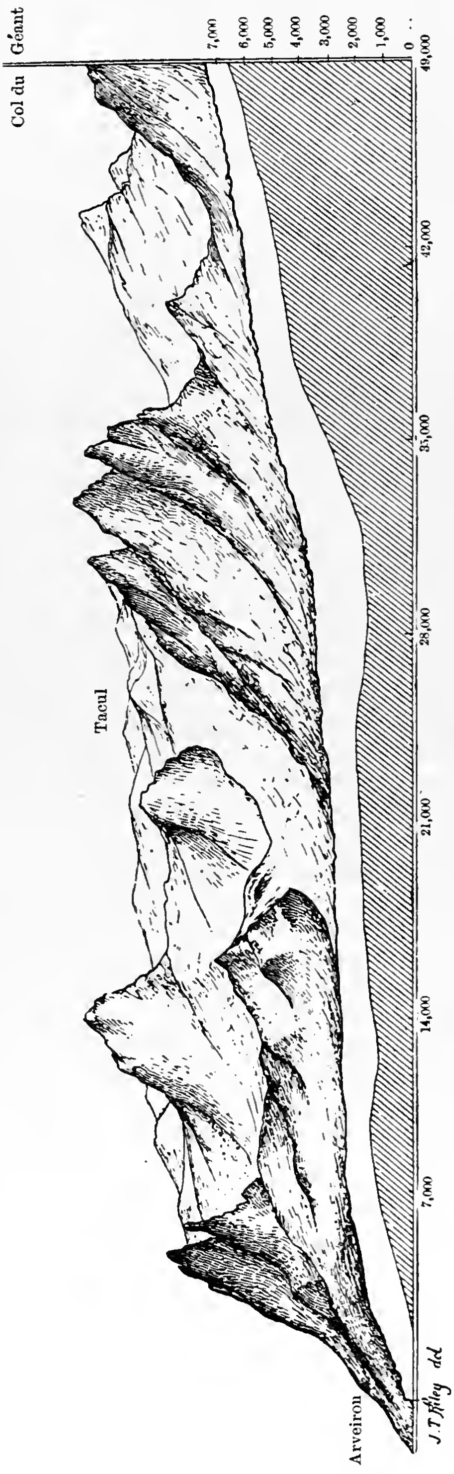


Fig. 1.—Sectional View of the Mer de Glace, from the Source of the Arveiron to the Col du Géant.
(*Drawn from the Measurements given by Principal Forbes in his "Travels in the Alps;" the figures represent feet.*)

But the question remains, how a solid and brittle substance like ice can behave like a liquid, flowing down gentle slopes and accommodating itself to its bed. There have been many attempts made by scientific men to explain the river-like motion of glaciers. The valleys in which glaciers lie are always inclined, and this led De Saussure, to whose early and excellent observations on glaciers we referred to in previous papers, to suggest that the weight of a glacier was sufficient to urge it down the slope, the accumulated snow above pressing it downwards, the motion being aided by the assumed liquefaction of the ice on the under surface of the glacier from the natural heat of the earth. But this "sliding theory" is not only insufficient to explain the liquid-like motion of a glacier, it is obviously inconsistent with facts;

for, among other reasons, even if the channel were perfectly smooth, instead of having, as is the case, an uneven and rocky surface, no *solid*, and therefore rigid, body would slide down unless the slope were much greater than it generally is in the glacier valleys. The accompanying diagram (Fig. 1), drawn to scale from Forbes's observations, will give some idea of the gentle slope of a glacier.

Another theory, proposed by De Charpentier, was to the effect that the glacier was pushed down by the force of expansion, arising from the freezing of water. The body of the glacier was supposed to be penetrated with minute fissures, which filled with water in the day and were frozen at night; and as water expands in freezing, this process, being constantly repeated, was supposed to account for the motion of the glacier. But this "dilatation" theory is still less in accordance with facts than the previous one. For in winter the glacier ought not, according to this explanation, to move at all, whereas it does; moreover, the changes of temperature between night and day are felt only to a very small depth below the surface of a badly-conducting body like ice; and, again, there is no evidence to show that a glacier is penetrated with minute fissures.

This was the state of knowledge on the subject when the late Principal Forbes began his glacier observations, which led to the publication of his "Travels in the Alps." Forbes first set to work to obtain accurate data, and the observations he made in 1842 he has thus summed up :—(1) That the downward motion of the ice from the mountains towards the valleys is a continuous and regular motion, going on day and night, without starts or stops; (2) that it occurs in winter as well as in summer, though less in amount; (3) that it varies at all times with the temperature, being less in cold than in hot weather; (4) that rain and melting snow tend to accelerate the glacier motion; (5) that the *centre* of the glacier moves faster than the sides, as is the case in a river; (6) that the *surface* of the glacier moves faster than the bottom, also as in a river; (7) that the glacier moves fastest (other things being supposed alike) on steep inclinations; (8) that the motion of a glacier is not prevented, nor its continuity hindered, by contractions of the rocky channel in which it moves, nor by the inequalities of its bed; (9) that the crevasses are for the most part formed anew annually, the old ones disappearing by the *collapse* of the ice during and after the hot season.

The consideration of these facts led Forbes to the conviction that the ice of a glacier behaved, not as a rigid body, like stone, but as a plastic or viscous body, more like dough or thick honey, though of course less fluid, and therefore less mobile, than these bodies. Now, a solid and a viscous body behave very differently on a gentle slope—the former moves as a whole, the latter has a movement of its parts analogous to a liquid. A mass of pitch will, after some time, spread itself over the surface on which it rests, through the continual action of gravity. According to Forbes, melting ice is a body of this kind, hence the gradual creeping of a glacier down into the lower valleys.* This theory he clearly states in the following passage :—"A glacier is a plastic mass impelled by gravity, having tenacity sufficient to mould itself upon the obstacles which it encounters, and to permit one portion to slide past another without fracture, except when the forces are so violent as to produce discontinuity, in the form of a crevasse, or more generally of a bruised condition of the mass so acted upon; that, in consequence, the motion of such a mass on a great scale resembles that of a river, allowance being made for almost incomparably greater viscosity: hence the retardation of the sides and bottom. Finally, that diminution of temperature, diminishing the plasticity of the ice, and also destroying the hydrostatic pressure of the water which fills every pore in summer, retards its motion, whilst warmth and wet produce a contrary effect."

This "viscous theory" subsequently met with vigorous opposition on the part of Professor Tyndall, who contended that ice, even at the melting point, was a rigid crystalline body, incapable of flexure, and therefore unable to flow and to mould itself to its channel. Dr. Tyndall thereupon proposed another explanation, based on the curious property possessed by thawing ice—namely, the freezing together of those surfaces which are in contact. This property was first carefully examined by Faraday, and named by him *regelation*. It can be observed any day in the fragments of ice at a fishmonger's shop. It is familiar to every one in the manufacture of a snowball; and it is by regelation that the "snow bridges" are formed which often

* The term *viscosity* has been defined by Prof. Tait as "an internal resistance to change of shape, depending on the rapidity of the change," and, therefore, expresses "molecular friction," which, in a less degree, exists in fluids, both liquid and gaseous, and in these bodies is generally known as the "viscosity of fluids." Frictional resistance to change of shape is not, however, quite the sense in which Forbes used the word viscosity, but rather the gradual yielding of the shape of a body under continued stress, to which the word *plastic* may more strictly be applied, thus embracing semi-solid and semi-liquid substances like mortar.

span the yawning chasms in the Alps. It is simply necessary to bring two fragments of ice in contact with each other, when they will immediately become cemented together. This, however, will be found to occur only with thawing ice—that is, with ice at its melting point—the surface of which is therefore covered with a film of water. If the experiment be tried upon a very cold day, when the thermometer stands some degrees below freezing point, it will be found not to succeed. Nor can a snowball be made under such conditions; even if vigorously squeezed it still remains a loose, incoherent powder. Both in the snow and the ice an exterior film of water is necessary, for it is the freezing of this film which glues the fragments of ice or particles of snow together.

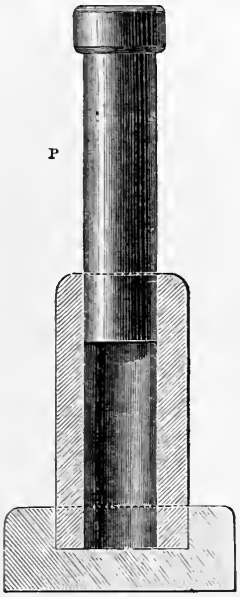


Fig. 2.—Iron Mould for subjecting Ice to Pressure.

The cause of this regelation we shall study directly; the fact of it occurring does undoubtedly account for the conversion of the discontinuous névé into the continuous ice of the glacier. Prof. Tyndall, however, went further. This distinguished physicist and Alpine traveller sought in regelation, as we have said, an explanation of the behaviour of a glacier; the mobility of which, he asserted, was apparent, not real. According to this theory, the ice is incessantly being broken and crushed by the strains and stresses to which it is subject; but after it has broken, regelation sets in, heals the wounds, and binds the ice once more into a continuous whole. By some interesting experiments on moulding crushed ice into various shapes, through the pressure exerted by an hydraulic press, Dr. Tyndall supported his theory of "fracture and regelation." The accompanying wood-cuts will show the shapes which ice can be made to assume by simply squeezing broken fragments powerfully together. Into an iron mould, shown partly in section in Fig. 2, crushed ice or snow is rammed; the solid piston P is then forcibly driven home, and a little cylinder of clear ice is produced. In like manner, the box-wood mould in Fig. 3, shaped like a cup and ball, is able to produce a cup of ice, and another mould a disc of ice; placing these parts in contact, regelation sets in, and freezes the whole together into a claret-glass, as shown in Fig. 4.

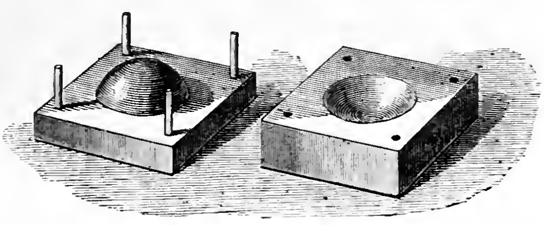
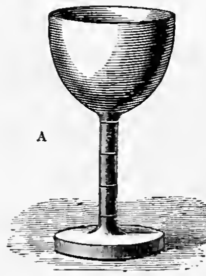


Fig. 3.—Boxwood Mould for Experiment, showing shape that Ice may assume under Pressure.



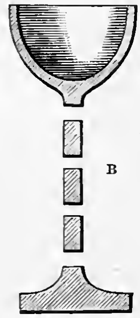


Fig. 4.—(A) Cup of Ice formed by squeezing its Component Parts (B) together.

When a Bramah press is not at hand, a large vice may be successfully used in making the foregoing pretty experiment. Magnify these moulds, as the eminent Swiss naturalist, M. De la Rive, has remarked, and they become the borders of the valley through which a glacier flows; the weight of the snow and ice above takes the place of hydraulic pressure; and gravity, incessantly in operation, causes the ice insensibly to accommodate its form to that of the valley. Thus ice seems to exhibit a plasticity like soft wax. But ice, the same writer continues, is plastic only under pressure, not under tension. This is the main fact on which the advocates of the fracture theory rely. Time and temperature are, however, overlooked, and the introduction of these elements changes the aspect of the case. Let us, therefore, look at the two theories in the light of recent experiments on ice.

Forbes's theory of glacier motion, as we have seen, rests upon the assumption that ice at its melting point is essentially a plastic body, and, like warmed sealing-wax, will bend in response to a gentle continuous pressure, though it will snap with a great and sudden strain. On the other hand, Tyndall's theory is based on precisely the opposite assumption: that ice is not plastic, but crystalline, in its structure, and brittle in its behaviour. Careful experiments on the possibility of

bending ice have been made. Canon Mozley, Mr. Mathews, and others, have shown that an ice-plank at the melting point *does* gradually bend under pressure, like a plastic body. More recent experiments made on the Continent by Bianconi corroborate this fact, thus proving that ice has a certain degree of plasticity, notwithstanding its brittleness. The ice-plank, though it can be bent by gradual pressure, is shattered to pieces by a slight shock. M. Bianconi has also shown that pebbles and other solid bodies can be pressed into the ice, penetrating it as they would a semi-fluid body, the particles of ice rising up in a ring around the intruded body. Another Continental physicist, Herr Pfaff, has ascertained the *amount* of pressure necessary to displace the particles of ice, and has proved that even the *smallest* pressure acting continuously is sufficient for this purpose if the ice and its surroundings are kept approximately at the melting point. Under a pressure of two atmospheres—say 30lbs. on the square inch—the ice, even at one degree below its freezing point, showed itself so yielding that a little hollow iron cylinder, half an inch in diameter, sank an eighth of an inch into the ice in a couple of hours. When, however, the temperature was four or five degrees lower, the cylinder penetrated the ice only one-sixteenth of an inch in twelve hours; and when the temperature was reduced to 18° Fahr. below the freezing point, the cylinder almost refused to enter the ice, penetrating only one-twenty-fifth of an inch in five days under a pressure of five atmospheres. In like manner the same observer has shown that an ice-plank suffers a scarcely sensible bending when the temperature is much below the freezing point, but that as soon as the temperature rose the bending was most marked and rapid, yet nowhere could the least trace of a crack be discovered.

These important experiments, which quite corroborate the opinions held by Forbes, based on observations long since made by M. Person, establish the fact that cold ice is a brittle, non-plastic body, but that ice near its melting point is a yielding, plastic body. It only remains, therefore, to ascertain the internal temperature of a glacier, both in summer and in winter—for, as already stated, the motion goes on in winter; then, if the temperature be found very much below the freezing point the viscous theory must be given up; if, on the other hand, the temperature be found at or near its melting point, the fracture theory must be relinquished as unnecessary, and less in accordance with the observed facts of glacier motion.

Thermometers have been sunk deep in the ice of a glacier, and careful observations made of the temperature of the ice at various seasons in the year. In every case the internal ice has been found close to its melting point. At the bottom of a hole bored 200 feet deep in the solid ice the temperature in summer was found to be $31\frac{1}{4}°$ Fahr., the melting point being 32°; and in winter-time in the same hole it was $28\frac{1}{4}°$ Fahr., this being an exceptionally low temperature. The swifter motion of the glacier in summer is thus readily accounted for. The streams of water—arising from the snow and ice melted on the surface—which, during the summer, everywhere penetrate a glacier, raise its temperature to the melting point; and in winter, when these streams cease to flow and hard frost sets in, the extremely low conducting power of ice for heat preserves the whole of the glacier, except its superficial portions, at a temperature little below the freezing point. Knowing these facts, it is difficult to withstand the conclusion that the viscous theory maintained by Forbes is a true interpretation of the flow of a glacier.

We need not do more than allude to the theory proposed by Dr. James Croll, which supposes a molecular motion of the ice. Here it is assumed that a progressive liquefaction of the ice particles takes place owing to the transmission of heat through the ice. This theory, however, breaks down from one fact, among others, that ice is not a conductor of heat, as assumed by Dr. Croll, though radiant heat is to a slight extent capable of traversing it. Radiation and conduction are, however, different things.

Having thus discussed the various theories of glacier motion, let us, in conclusion, endeavour to understand that beautiful process of re-freezing, or *regelation*, whereby the ice of a glacier continues a compact mass in spite of its perpetual movement and incessant fractures. The explanation of regelation, like the cause of glacier motion, has given rise to considerable diversity of opinion. Faraday viewed the action somewhat in this way:—A greater freedom of motion is enjoyed by a liquid than a solid; this freedom is first gained by the water at the surface of the ice, for here the particles are bounded on one side only by the solid mass, and by the atmosphere on the other. Some controlling action may be assumed to be exerted by the particles of the solid on the one side. When a second piece of ice touches the first, the layer of water is squeezed away at the points of contact to the thinnest possible film, and this film finds itself bounded by solid surfaces on both sides.

"The liberty of liquidity," as Prof. Tyndall puts it, "at each point where the surfaces touch each other is arrested, and the two pieces freeze together at those points." In this explanation it is difficult to account for the escape of the heat which is liberated by the passage of the water into solid ice. This difficulty is got rid of by regarding the interior of the block of ice as colder than the exterior, the heat diffusing itself by conduction into the mass.

Experiment shows that the interior of a block of ice *is* slightly colder than the exterior, and upon this fact Professor Forbes founded a different and fuller explanation of regelation. The surfaces of two blocks of melting ice which are brought together are virtually transferred from the exterior to the interior. The ice on both sides of the enclosed layer of water will now be colder than the water, and a new distribution of heat accordingly takes place, the result of which is that the water is frozen, as it is now in the central, and therefore coldest, part of the block.

A third explanation of regelation has been given by Professors James and Sir William Thomson, founded upon the important fact, which they first established, that the temperature at which water freezes may be slightly lowered by strong pressure. If, therefore, ice at its ordinary freezing point, 32° Fahr., be squeezed, it tends to become liquid, and when considerable pressure is used liquid films may be seen within the ice. Upon the removal of the pressure the freezing point rises, and the liquid films again become ice. This action, according to the eminent philosophers just named, is sufficient to account for the fact of regelation. It may be urged, however, that the pressure is too slight for liquefaction by this agency to come into play. This objection may be met by supposing, what is doubtless actually the case, that under a feeble pressure the fragments of ice will only touch in a few—practically three—points, and upon these the whole of the pressure is concentrated; a feeble *total* pressure may, therefore, be a very considerable *local* pressure at the points of contact. Under this stress, a trace of ice will melt, and on the removal of the pressure the water formed will freeze. The beautiful experiment, suggested by Mr. Bottomley, and already described and figured in another paper,* illustrates the preceding fact.

In the case of a glacier, the water produced between the pieces of ice which are pressed together can escape through the numerous cracks which penetrate the glacier; and as it runs away, not only does it escape the pressure, but it also carries with it the heat necessary for its liquefaction. Under these conditions the pressed ice becomes colder than zero, owing to the lowering of its freezing point by pressure, and this cold ice finds itself in contact with water at the zero temperature. The result is that a continual freezing of some of the escaping water takes place, new ice thus forming round the portions which are pressed, whilst these are simultaneously undergoing a slight superficial liquefaction. Thus Helmholtz has explained how the cementing of the masses of ice by regelation may occur even when the pressure is unrelaxed, provided that cracks exist in the ice to allow some motion to the liberated water.

Each of these rival theories has at the present time eminent advocates;† hence the explanation of regelation may be regarded as still an open question, notwithstanding the severe discussion of the subject which has taken place in the scientific world. It is not improbable that all three causes are to some extent operative, and that under particular conditions one or other comes more permanently into play. Broadly viewed, the theory of Forbes seems to the present writer most consistent with observed facts, and, therefore, likely to be more generally true.

Before bringing this necessarily brief talk on glaciers to a close, we must not omit (though unconnected with the subject of the present paper) a brief notice of a beautiful structure developed in ice when a beam of luminous heat is passed through a slab of ice, cut parallel to its plane of freezing. Exquisite six-sided stars are then seen forming within the ice; these are composed of water arising from the slow disintegration of the ice crystals. There is also a shining central spot, which is vacuous, as the bulk of the water is less than that of the ice from which it was derived. It is easy to witness for oneself this interesting phenomenon, first noticed by Dr. Tyndall. All that is necessary is to procure a block of clear ice, saw a slice parallel to the plane of freezing—which can generally be discerned by the air bubbles or by other means—smooth the sides by rubbing on a warm metal plate, hold the slab close to a lamp or gas flame, and during its liquefaction observe the ice, assisting the eye by a lens. The swift formation of the pretty six-petalled liquid flowers will then be instructively and distinctly

* "Science for All," Vol. I., p. 32.

† *E.g.* Dr. Tyndall supports Faraday's view; Dr. Balfour Stewart Forbes's, and Professors Helmholtz and Tait, Thomson's explanation.

seen. As might be expected, there is a striking resemblance between the general shape of these "ice flowers" and the lovely snow crystals that are sometimes seen in such wonderful perfection. Indeed, few things in Nature are so full of interest to the diligent student as water, whether as solid, liquid, or vapour. And so every familiar object has its tale to tell, and will yield untold pleasure and unsuspected wonders to the patient and thoughtful inquirer.

DUST.

By W. C. Williamson, F.R.S.,

Professor of Natural History in the Owens College, Manchester.

MARCH and March winds bring with them practical reminders of the existence of that of which a peck, at the right season, is said, by an old adage, to be worth a king's ransom. Ordinary observers see in the March dust only a sign that the agriculturists are being favoured with a season adapted to their spring labours, and an indication that they must themselves take more than ordinary care of their eyes. But science sees something more than this. It discerns in the dust the results of a long and extremely varied series of operations, some of which are due to inorganic and others to organic agencies, whilst the product of these combined agencies becomes itself a means towards the accomplishment of still further ends.

There must have been an immeasurably long period when no dust existed upon the earth—viz., when the globe was a rolling sphere of fluid material, heated to such a temperature as made that fluidity permanent, without which supposition it is difficult to account for its spherical form; yet we are equally unable to arrive at any exact knowledge as to what it then consisted of, and what its atmospheric surroundings were. One thing, however, may be regarded as certain, that there were placed side by side in the fluid sphere the same elementary bodies as now constitute its substance—that oxygen existed in the neighbourhood of oxydisable bodies, that sulphur was capable of volatilisation, and that if vapour came in contact with common lime the latter would then, as now, fall into powder. The results of these and other similar agencies would necessarily be the disintegration of hard materials wherever the fluid elements cooled down sufficiently to admit of their becoming hard.

It is a generally accepted belief that the early stages of cooling, which reduced our globe from a fluid to a solid state, must have led to many disturbances that were essentially volcanic in their nature. Radiation into an atmosphere colder than the sphere from which the heat radiated would naturally cause that sphere to harden at its surface, and such hardening would inevitably lead to contractions of the hardened part upon the less contractible fluid nucleus. Hence fissures or cracks, and the violent rubbing of one hardened surface against another, which would produce what would be a primeval form of dust. How largely such a formation of dust is associated with volcanic action is shown in the vast quantities of it which so frequently darken the air whenever a serious volcanic eruption takes place. But this friction would not stand alone as a dust-producing agent. When the earth's crust was sufficiently cooled to allow of such operations as we have referred to, the surrounding air would also be sufficiently cooled to allow of the condensation of vapours and the consequent production of showers of rain. These would at once introduce a new dust-forming power. Oxydisable elements—such, for example, as calcium and iron—would rapidly pulverise under atmospheric influences, and each succeeding shower of rain would not only expose fresh surfaces to similar agencies, but by the friction of its tiny streamlets would add one more to their number. Thus, so far as inorganic agencies were concerned, the forces capable of forming dust must at this early period have commenced their operations. Time, with its whirligig changes, would only multiply the variations in the *modus operandi* of air and water, as well as the localities which successively become fitted for their action; whilst one important result would be the addition of a new compound to those already constituting the earth's substance—viz., that mixture of dust and water which we call mud.

To see that the physical and chemical characteristics of the dust produced by these agencies must be as varied as those of the pulverised rocks from which it was derived, requires no philosophy

on the part of our readers. Some atoms, derived from crystalline materials, would be sharp and angular, and in the infancy of the world's being such would probably be the predominant ones, since the cooling of materials from a state of fluidity, resulting from excessive heat, would tend to leave them all in more or less crystallised forms. But as watery agencies increased in power, more amorphous forms would gradually make their appearance; and since all the changes of the seasons, with their varying phases of climate and meteorological conditions, would be the same then as now — since our northern part of the sphere, for example, whatever its geographical arrangements might be, would have in all probability its wet seasons and its dry ones, representatives of its March winds and its July rains—we may fairly conclude that those winds would raise the dust, though in smaller quantities, somewhat as they do now. But we must also remember that, since narrow roads and traffic, with their innumerable rolling and crushing wheels, would not then exist, such clouds as now assail us on a dry and windy spring morning would not be so conspicuous then as they are now. Such clouds belong to the streets and highways rather than to moor and mountain, apart from the dust-preventing instrumentality of the vegetable world.

But with the introduction of organic life new elements would enter into the composition of dust. However firmly we may hold the doctrine of evolution, we can scarcely even speculate on the exact order in time in which these new elements made their appearance. But we can learn something of what those elements are that chiefly enter into the composition of dust at the present time. The study of this portion of the subject is a very recent one, but it is one of great importance to the well-being of the world. Before, however, making any observations upon it we must somewhat extend our ideas in speaking of dust. Instead of confining our notions to what we can see with our eyes when the wind is driving conspicuous clouds before it, we must include in the term *all* the atoms, visible or invisible, organic or inorganic, that float in the air. When sitting on a sunless day in a quiet room, we are unconscious of the existence of any foreign atoms in the air which we breathe. But if we admit a bright beam of sunlight into such a room, and look through it in a direction more or less perpendicular to its course, we at once see that the atmosphere is charged with minute floating particles, previously invisible to us. Professor Tyndall made valuable use of a similar method of illumination when conducting his interesting experiments on germs: experiments bearing upon the problem of spontaneous generation. He transmitted a beam of bright light through a darkened box, in such a direction that it was invisible to the observer, excepting when it was reflected from the surfaces of the atoms floating in the atmosphere. By this means he was enabled to trace the gradual deposition of the atoms when, currents

Fig. 1.—Dust Collected on a Sheet of Paper Exposed at Montreux. (*Magnified 500 diameters.*)

being excluded, no power remained causing them to continue to float. It is the subsidence of these atoms that renders necessary the domestic process of "dusting" our rooms—a process which, as too often performed, only means disturbing the particles from the surface upon which they have fallen, and restoring them to the atmosphere from which they fell. But it is not only the confined atmosphere of our dwelling-houses that is thus laden with foreign particles. The outside air is full of, though less densely charged with, similar ones. Various methods have been tried, having for their object the collection of these floating atoms, with the aim of exposing them to microscopic investigation. One of the most successful of these methods has been to cover a plate of glass with a thin coat of glycerine, and to expose it to the outside air, with its moistened surface facing the quarter from which the wind blows (Fig. 1).

These experiments have not yet afforded us such absolute demonstration of the nature of these aërial particles as might have been hoped for. We learn more about them from a process of deductive reasoning, the result of experiments that nature is everywhere making for us, than from our own direct investigations. The unaided processes of normal putrefaction and fermentation—the development of microscopic forms of animal and vegetable life in fluids in which they were previously non-existent—the speedy manner in which nature clothes barren spots with moulds, lichens, and other forms of cryptogamic vegetable life, and even the similar development of crops of some kinds of flowering plants on newly exposed soils, all require for their explanation the existence of the germs of these varied objects floating in the air. To a certain extent the practical microscopic analyses of the organic contents of the atmosphere, made in the way already referred to, have justified the hypothesis which accounts for the phenomena just mentioned by supposing that the germs of the objects discovered do abound in the atmosphere. But in the case of many of them, these germs, indiscriminately collected, are too small and too devoid of distinctive features to be thus identified. We easily recognise the particles of mineral matter captured by the glycerine process. Pollen-grains from flowers and atoms of vegetable hairs and fibres are sufficiently distinct and numerous; but when we come to many of the minuter organisms, though their germs are unquestionably present, they are not so easily identified.

We may ask what the facts are upon which these statements rest, and the reply comes from a thousand quarters. We learn that the conclusions arrived at are the only ones to which the facts can lead us.

This is not the time or place to do more than summarise a few of the results of the experiments of Pasteur, Tyndall, Roberts, Dallinger, and others, nearly all of which teach the same truth—viz., that when solutions of animal or vegetable substances have been exposed to such high temperatures as destroyed all traces of animal and vegetable life, if the air were allowed to obtain free access to such solutions they were speedily re-peopled with objects similar to those which had disappeared. The atmosphere was, in such cases, the only medium through which these minute organisms were re-introduced into the solutions. A rotting apple is allowed to remain neglected in some corner of a closet, and there springs up from its decaying surface a crop of one or more forms of Mould. Two such apples, obtained from the same tree, and otherwise identical in every respect, shall be similarly exposed in two different closets; the one may become covered with one species of Mould, and the other with a different one. Such differences as these have been observed to result in the case of experiments conducted within a few inches of each other, and can only be explained on the supposition that the germs of various species of Mould were floating in the air, and that some of one species fell upon one apple, whilst those of a different species reached the other. These spores are so exceedingly minute and light, even when freshly gathered from their parent plant, that they float before the breeze with the greatest readiness; but when dried up—a process which they are capable of enduring without any loss of their vitality—they become almost imponderable: hence feeble atmospheric currents are capable of carrying them into the most remote and sheltered corners. That they mingle freely with the visible dust is shown by the observations to which I have referred: though it is difficult, perhaps impossible, to identify the spores of these Moulds and other fungoid plants with absolute certainty, since objects that are not distinguishable from them are also readily caught in the glycerine traps to which I have referred.

But yet smaller germs have been shown by Dr. Tyndall, Mr. Dallinger, and others, to abound in the air. The microscope reveals the presence in decomposing animal and vegetable solutions of myriads of those lowest forms of plant-life known by the names of *Baccillus*, *Vibrio*, *Spirillum*, *Bacterium*, &c. It is impossible to determine with certainty whether some of the reproductive germs in question

are those of plants or animals; besides which, these germs are so minute that, though they can be measured, and their diameters can be represented by fractional symbols, such symbols convey little or no definite idea of their actual minuteness to the human mind. Most of these germs are alike harmless to man and beast; but it is not so with all. One form, when introduced into the blood system of the mouse, brings on what is termed splenic fever, which destroys the animal in forty-eight hours. Similar ones produce another disease in the pig. These are accurately ascertained facts, rendering it extremely probable that many of the diseases from

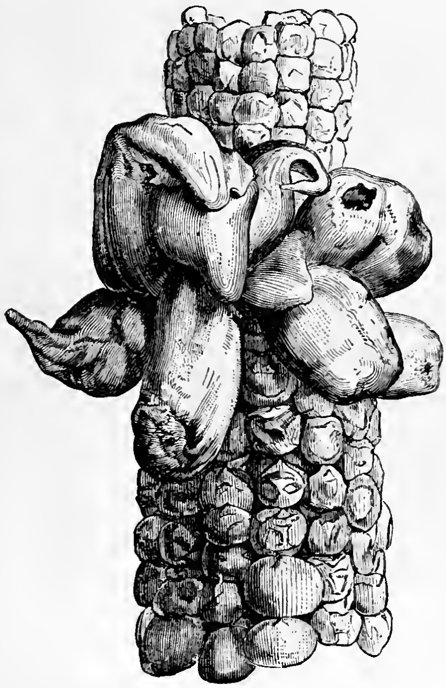


Fig. 2.—Smut on Maize.

which the human race suffers are brought about in the same way. We know already that such is the case with some skin diseases—for though absolute contact is necessary to convey the contagion in some of them, in others the evil springs up so inexplicably as to make it extremely probable that the germs generating the disease are derived from aërial sources. It is the introduction of similar germs that makes milk go sour and exposed blood become putrid.

When we turn from the diseases that affect the animal to those seen in the vegetable world, we discover that similar phenomena are of common occurrence. The destruction of our potato crops, some thirty or more years ago, and the wide-spreading mischief that played such havoc amongst the vines in the wine-producing countries before the discovery of the beneficent power of sulphur to control the evil, are well-known examples of the results of spores floating in the atmosphere. Still more familiar illustrations of the same thing are seen in the case of the diseases of wheat and oats known as Rust and Smut. The germs of the plant producing the former disease are produced on the leaves of the barberry; but they can be made to germinate only on the ears of wheat, to which they have to be conveyed by the wind and other agencies. The black Smut of the oat is another example of vegetable dust freely carried by the wind, and germinating when reaching plants similar to that on which it was developed (Figs. 2, 3, and 4).

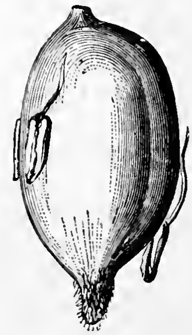


Fig. 3.—Bunted Grain of Wheat.

The disease known as Hay Fever, from which many persons suffer so seriously in spring-time, is supposed by many to be another of the results of the prevalence of vegetable dust in the atmosphere. It is supposed to arise from the minute pollen grains detached by the wind from the anthers of the numerous grasses which bloom at that season. This hypothesis receives some support from the fact that sufferers from the disease frequently obtain relief by hiding themselves in the lowest and most central parts of our large cities, where no hawthorn scents the breeze, and where waving meadows are alike out of sight and out of mind.

Pollen of other plants, in which the male and female structures are found on different individuals, is doubtless, in some cases, conveyed by the wind, though in all probability the effect of the vegetable dust thus conveyed through the air is but small compared with that carried from tree to tree through the more direct instrumentality of honey-loving insects.

Fig. 4.—Bunt on Wheat.

There is one form of dust of a peculiar kind which must not be left unnoticed. That is the

dust of the microscopist's study, which in more than one instance has vitiated the trustworthiness of the observations of some of our most distinguished men of science. Every microscopist is familiar with the minute siliceous vegetable organisms known as *Diatomaceæ* (Fig. 5). There is hardly one observer who has not delighted in their practical study at one period or other of his career. Being very minute, as well as very light, they float freely in the atmosphere of the laboratory, and find their way into places where they are not wanted. Ehrenberg announced that he had discovered these objects amongst the marine foraminiferous organisms (Fig. 6) that constitute the ordinary chalk of this country; but though innumerable observations have since been made upon

Fig. 5.—Diatoms.

this chalk, none of Ehrenberg's successors have been able to verify the distinguished Prussian's alleged discovery. There is no doubt but that the atmosphere of his study was laden with these minute Diatoms, and that in preparing his specimens of chalk for microscopic observation some of their siliceous frustrules found their way intrusively into his preparations. It is only in this way that another alleged discovery can be accounted for. Count Castracane, some time ago, announced his discovery of numerous forms of similar Diatoms in the incombustible ash left after treating coal with heat and various chemical re-agents. Several other observers, whose competency is beyond question, have repeated his observations and accurately adopted his methods. But one and all have failed to detect the slightest trace of these Diatoms. I have little doubt but that the explanation of these discrepant observations is to be found in the peculiar atmosphere of the Count's study. It will be remembered that after Professor Tyndall had conducted a series of observations on the development of minute germs in previously heated fluids with perfect success, the atmosphere of the place became so laden with these germs that no amount of care sufficed to exclude them from the tubes within which he was carrying on his observations. On removing his apparatus to the purer atmosphere of the Kew Gardens, he had no difficulty in obtaining

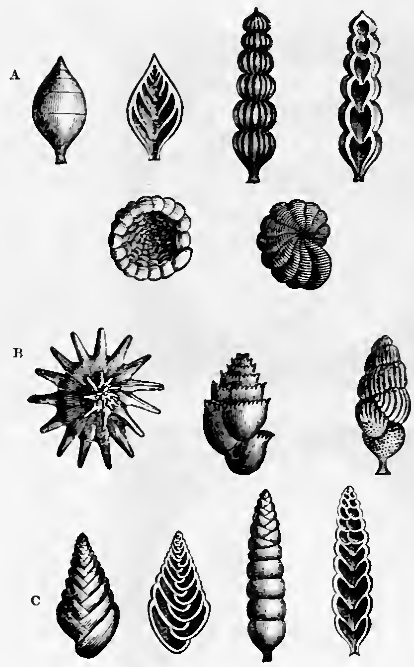


Fig. 6.—Foraminifera: (A) Stichostega; (B) Helicostega; (C) Enallostega.

the same satisfactory results that he had previously obtained at the earlier stages of his investigations in his laboratory in Albemarle Street.

Ehrenberg made one series of observations affording results which are probably not capable of a similar explanation. He found that the layers of volcanic Tufa which overlaid some of the Vesuvian buried cities contained numerous Diatoms. This Tufa had once been in the condition of volcanic ash, the finer particles of which are not unfrequently carried through the air by the wind hundreds of miles away from the volcano whence the dust originated. It seems more than probable that in this instance the siliceous organisms had been conveyed into the interior of the crater by means of the sea-water, which is now recognised as

playing so important a part in the disturbances connected with volcanic eruptions. The fact that Ehrenberg found similar organisms in the pumice recently ejected from existing craters seems to support the explanation referred to. But, whatever may have been the way in which the Diatoms reached the interior of the crater, there appears to be little reason for doubting that their siliceous cell-walls do sometimes form an integral part of the volcanic dust discharged from its fiery gorge.

I have thus far said little about the animal constituents of dust; nevertheless, such undoubtedly exist. There is no question that the germs of many of the lowest forms of animal life are as capable of being dried up, and of being transported by aërial currents, as are the vegetable organisms to which I have already referred. Many of the minute Monads described by Dallinger and others are found under circumstances that can be explained only on this supposition. Besides which, we have demonstrative evidence that the sediment accumulated in the gutters and spouts of our house-roofs abounds in Rotifera (Fig. 7), objects having a far higher organisation than these Monads possess. Baked up during protracted seasons of dryness, this sediment is blown hither and thither, and yet the organisms which are mingled with and form a part of it do not perish. The well-known case of the highly-organised *Rotifer vulgaris*, or common wheel animalcule, affords the best example of this tenacity of life. How great this tenacity is may be realised from the following fact:—Some years ago I received from the Rev. Lord Sydney Godolphin Osborne a small pill-box filled with impalpable dust. It had been in his lordship's possession in a dried state for some months before he sent it to me. On putting a little of this dust under the microscope, and adding a drop of water to it, it soon underwent a marvellous change. At first it appeared to be wholly composed of inorganic particles, but in less than a minute some of these particles began to move, and in about a couple of minutes more the water abounded with fully-grown and unmistakably hungry examples of the wheel animalcule. In that brief period their dried-up tissues imbibed moisture, swelled out to their normal form and dimensions, and every organ of their bodies was seen actively performing its destined functions. The cilia of their wheel organs were in full play, and in a very few minutes more their stomachs were becoming gorged with the indigo and carmine with which I fed them. It might be urged by some honest doubter that these creatures had emerged from eggs that endured the process of being dried up with impunity; but such was certainly not the case. The eggs of these Rotifers are large and easily recognised; besides which, the young animal that first emerges from the ovum requires a much longer time to develop into its matured form, than elapsed between my adding the drop of water to the dust and the perfect expansion and full activity shown by every organ of these Rotifers. The dry dust in question continued to exhibit these results for nearly six months after it came into my possession; but nature had its limits of endurance. After six months had elapsed I failed to discover any traces of life in the contents of my pill-box.

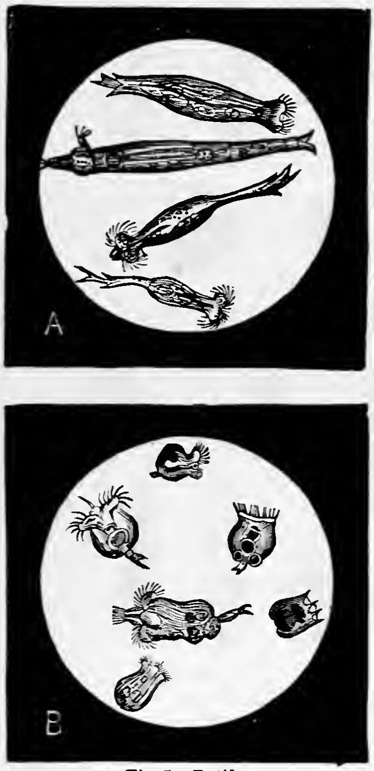


Fig. 7.—Rotifera.
(A) Rotifer vulgaris; (B) Brachions.

Recent experiments have demonstrated that one form of dust is calculated to add seriously to one of the most destructive forces that overtakes large bodies of the men who minister to our daily wants. For some time past attention has been drawn to the inflammability of fine coal-dust. Like the Lycopodian spores long employed to produce, by their instantaneous combustion, the effects of lightning, when such effects were required for dramatic purposes, coal-dust, when sufficiently fine, proves to be remarkably inflammable. The galleries of dry coal-mines abound in dust of this character. Though originating in special portions of the mine, the powerful currents of air required for purposes of ventilation necessarily diffuse this dust through the workings. So long as the atmosphere undergoes

no disturbance beyond what is produced by these ventilating currents, no material mischief is done by the dust; but when explosions of fire-damp occur, it is more than probable that the terrible destructiveness of the inflammable gases is seriously increased by the sudden combustion of the particles of coal-dust floating in the atmosphere of the mine. Mr. R. H. Scott, Secretary to the Council of the Meteorological Office, has presented to the Royal Society two memoirs illustrating the effects of explosions occurring in such a mixture of coal-dust and atmospheric air. His experiments demonstrate how seriously the coal-dust adds to the force of the explosion, and lead him to conclude that "where there is no coal-dust in the gallery the flame of the fire-damp explosion does not extend further than from seven to nine feet from the bottom of the explosion chamber. When the gallery contains coal-dust, on the other hand, on the floor and on the shelves referred to, and when it is filled with the return air of the mine, the explosion traverses its whole length, and shoots out into the air to distances varying from four to fifteen feet. The flame of the fire-damp explosion is thus magnified ten times by the presence of the coal-dust and the return air." Of course, the measurements mentioned in this quotation from the abstract of the second memoir presented to the Royal Society refer to the ingenious apparatus by means of which Mr. Scott conducted the experiments recorded in his paper.

One more curious form of dust may be mentioned. For some time after Bruce's return from his celebrated Abyssinian travels, a tradition floated through society that his party, penetrating an Abyssinian forest, had forced their way through a grove of dried Euphorbiæ, and in doing so had raised such a dust that the entire party sneezed incessantly for three subsequent weeks. The exaggerated rumour was not without a foundation. Bruce indicates the tree by its native name of the kalgual, and says of it:—"When the tree grows old the branches wither, and in place of milk the inside appears to be full of powder, which is so pungent, that the small dust which I drew upon striking a withered branch seemed to threaten to make me sneeze to death. The touching of the milk with my fingers excoriated them as if scalded with boiling water." It may be added that Sir Joseph Hooker found in Morocco a "sneezing plant" (*Euphorbia resinifera*), which secretes a caustic juice, that hardens into a gum. "The people who collect the gum are obliged to tie a cloth over their mouths and nostrils, to prevent the small dusty particles from annoying them, as they produce incessant sneezing." Sir Joseph's description of this plant* shows that it is either identical with, or closely allied to, that figured by Bruce in his work, as subjecting him to a similar sneezing process.

Enough has probably been said to demonstrate how varied a material the dust of the earth is, and how little we need wonder that it has latterly been credited with the power of producing hitherto unexpected results. In this respect the progress of time has led to the substitution of true for false ideas. The old Romans had their notions as to what dust could do. Thus Pliny says, in his "Natural History:"—"Dust, too, is productive of worms in wools and cloths, and this more especially if a spider should happen to be enclosed in them: for, being sensible of thirst, it sucks up all the moisture, and thereby increases the dryness of the material." Dust, as our cleanly housewives can certify, has sins of its own to answer for; but it was too bad of the old Roman to lay the mischief done by our clothes and curtain-eating *Tineidæ* at its door.

A PIECE OF ROCK SALT.

BY DAVID BREMNER, AUTHOR OF "THE INDUSTRIES OF SCOTLAND."

THOUGH man derives his chief supply of food from the animal and vegetable world, there is one condiment that is considered a necessary of his existence for which he is indebted to the mineral kingdom. That is salt, chemically chloride of sodium, or, as more modern chemists style it, sodium chloride, a substance abundantly distributed over the greater part of the earth, and stored in untold quantities in the waters of the ocean. Here is a piece of the mineral in its rock form. It is almost as heavy as a bit of sandstone of similar bulk, resembles alum in hardness, and is of a dirty red

* Hooker and Ball: "Journal of a Tour in Marocco and the Great Atlas"

colour streaked with transparent white veins. We might have chosen a purer sample, but the impurity gives us an opportunity of explaining that only a small proportion of the beds of rock salt which have been opened up have been found free from an admixture of foreign substances. Were we to analyse this specimen, we should find that its colour and dulness are due to the presence of iron-rust (p. 41, Vol. II.), sulphate of lime, and probably some clay. Other samples might differ in colour, and yield potassium chloride, calcium chloride, and magnesium chloride. Even in the refined salt some of these substances are present, but in minute quantities. The crystalline structure of salt is almost obliterated in the rock form, and if we chip off a piece it will be observed that it presents a foliated or fibrous texture. The outside of the lump is moist to the touch, owing to the affinity for moisture of some of the alien ingredients. Pure chloride of sodium retains a perfectly dry surface, and a remarkable property it possesses is that of freely allowing the passage of heat rays. Of 100 rays of heat a slab of clear rock salt will transmit ninety-two, while plate-glass transmits only twenty-four, and clear ice none at all. This fact is of great value to the scientific experimentalist.

Deposits of rock salt occur in various parts of Europe, the most extensive and best known on the Continent being in the province of Galicia in Austria, the area of which has been computed at over 10,000 square miles. The towns of Wieliczka and Bochnia are the points at which the vast field is chiefly worked. Mining operations have been carried on for several centuries, and marvellous stories are told of the extent of the excavations. It is said that in one mine the workings are over thirty miles in length, and that the salt in some places has been cut away so as to form great halls a hundred feet in height. In Asia and Africa there are numerous saline deposits, and the same can be said of America.

Where have these deposits come from? Geologists have long puzzled over this question, and even yet they are not quite agreed on the matter. Some attribute them to volcanic agency, but the bulk of testimony appears to be with those who assign to them a watery origin. It is clear that they do not belong to any particular geological period, for while the deposits existing to the north of the Carpathians are in the formations of the Tertiary Epoch, those in this country are in the Permian and Triassic, and those in America appear a long way farther down the scale. In proof of the theory that the salt was precipitated from water surcharged with saline matter, it is pointed out that such a process is now going on in the case of the Dead Sea, the Caspian, the Sea of Aral, and other land-locked bodies of salt water, in all of which salt is being deposited as the proportion between the bulk of the water and the saline matter introduced by tributary streams is changed to favour that result.*

But we must return to our particular piece of rock salt, and give some account of its birthplace and surroundings, which, being within the borders of the United Kingdom, have a special interest for us. It came from the great saliferous beds that underlie the valley of the river Weaver in Cheshire, the chief source, not only of the salt used as food, and in the chemical manufactures of this country, but of much that is consumed in other parts of the earth. There are deposits of salt in Worcestershire, Staffordshire, several of the northern counties, and in County Down, but these are insignificant in comparison, and yield only a fraction of the quantity drawn from the Cheshire field. The latter has an area thirty miles in length by from ten to fifteen miles in breadth, and at its richest part it contains two great layers of rock salt, the upper of which is from eighty-four to ninety feet in thickness, and the lower from ninety to 170 feet. Over this great mass of mineral stand the towns of Northwich and Winsford, the chief seats of the salt industry. It is only two centuries since the mineral in this locality was discovered, though salt had been made from the brine springs and pits from time immemorial. As the upper stratum of rock contains a considerable proportion of earthy impurities, the mines sunk into it were for the most part abandoned, when the existence and purer quality of the lower stratum were revealed, and the mining now in progress is chiefly confined to the centre of the latter, where there is a layer of comparatively pure salt from twelve to fifteen feet in thickness. As this gets worked out, of course, there will be a falling back upon the portions of the deposit at present neglected.

The Marston mine at Northwich, to which visitors are readily admitted, is one of the most extensive in the district, and is a highly interesting sight. It has been excavated to a height of sixteen feet over an area of about forty acres. The roof is supported on huge square pillars of the native rock left at regular intervals of about ten or twelve yards by the excavators. Both roof and floor have been cut

* See "Science for All," Vol. II., p. 28.

level, and the latter is covered with a coating of pulverised salt, as dry and as easily disturbed as the dust on a macadamised road on a fine summer day. The air is dry, sweet, and cool, the temperature from one year's end to the other varying little from 53° Fahr. Even in the feeble light afforded by the few candles carried by a group of visitors and their guide, the surfaces of the pillars and roof display most beautiful effects, and at many points appear to be encrusted with gems. Like the sample we visitors coloured lights are ignited by the guide, who for that purpose removes to a distance of a hundred yards or so. The effect of the light is magical. It reveals for the moment the vastness of the subterranean chamber, and brings out the pillars in full relief. The beauty which even the candle rays enabled one to discover is now intensified a hundredfold; and a person of an imaginative turn of mind might well suppose that he was enjoying the splendour of the scene of Aladdin's adven-

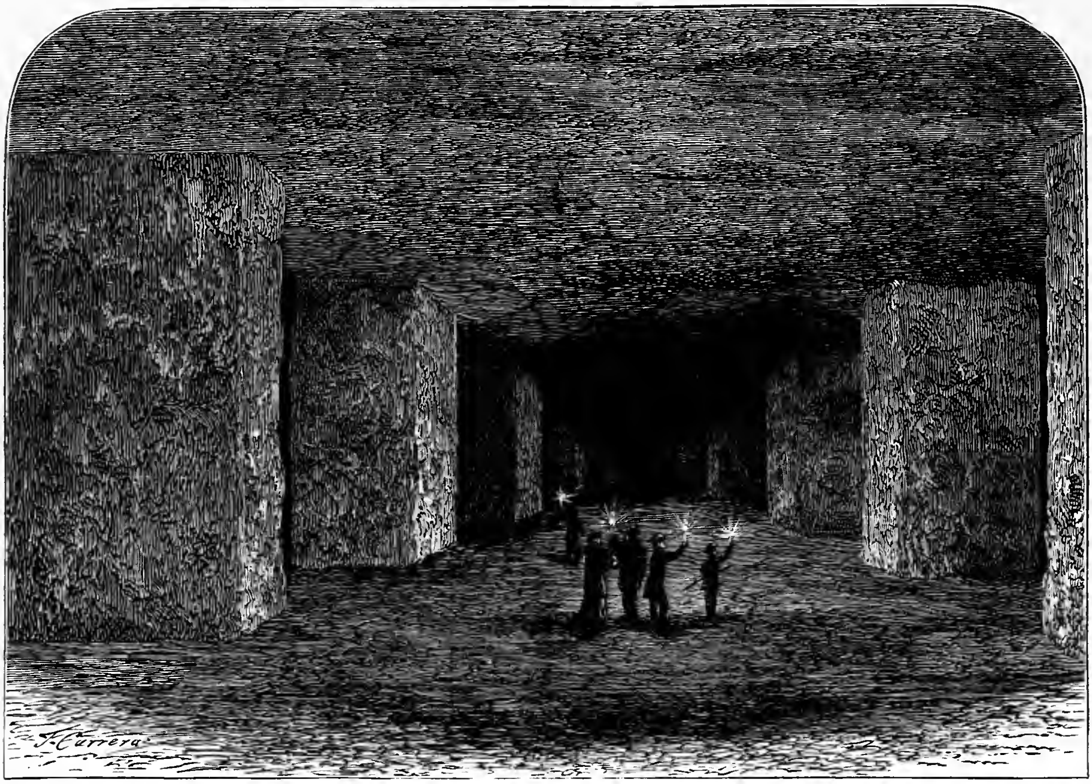


Fig. 1.—Interior of a Salt Mine.

have before us, the rock is of various hues, passing from deep red to transparent white, with here and there a touch of yellow. An examination of the roof reveals a striking peculiarity in the formation of the salt rock. It appears to be composed of masses of varied figure, and of different sizes, and has the effect of an irregular species of mosaic work. The outlines are in some cases circular, in others oval, but for the most part pentagonal, and the separate forms measure from two to twelve feet in diameter. The boundary line of each block is composed of a streak of white from two to six inches wide, and inside this the mass generally becomes darker towards its centre. For the delectation of tures. The play of the light among the pillars is especially striking; long vistas being opened up here, and dark shadows thrown athwart floor and roof there, while the vision is bounded by what appears to be a barrier of darkness solidified (Fig. 1).

Just as the last of the coloured lights is dying out, a terrific peal is heard and a noise as of thunder sweeps through the mine, echoing and re-echoing for several seconds. The alarm which this unexpected occurrence naturally creates in the mind of the unaccustomed visitor is allayed by the explanation that the noise was merely the report of a blasting-charge fired by the miners in the course of their operations. The guide having rejoined his

party, an advance is made to the extremity of the workings, where the miners are engaged, and here the manner in which our piece of rock salt was wrenched from its native bed is seen. As supplied for domestic use, salt is a more or less powdery material, but as it is found here, four hundred feet below ground, it is very compact, and requires quite as much force and skill to quarry as coal. The miners attack the face of the rock and cut perpendicular grooves in it. From these they drive bores right and left, which they charge with powder, and thus blast down the salt. To cut it out with the pickaxe would be a tedious process, chiefly because the mineral is not stratified, nor does it separate readily at the veins.

On being removed to the mine-head the larger blocks of salt are picked out and placed in trucks for removal to the chemical manufactories, or to a seaport for shipment abroad. A large proportion goes to the former, in which it plays an important part; and if we elected to send our sample thither and follow its transmutations we should witness some grand achievements of science and have revealed to us the many valuable services which salt renders to the arts. The great alkali manufacture of this country, which constitutes the wealth of several important towns, has its foundation in the Cheshire salt mines.

Salt and its various products constitute indispensable auxiliaries in dyeing, bleaching, paper-making, pottery-making, glass-making, various metallurgical operations, &c. The chemical designation of salt (chloride of sodium) indicates its composition when obtained in a pure state, and the first operation of the chemical manufacturer is to separate the sodium from the chlorine. This is done by treating the salt with sulphuric acid (oil of vitriol). As the sodium has a stronger affinity for the vitriol than for the chlorine, it separates itself from the latter, and combining with the vitriol forms sulphate of soda, or, as it is commonly called, "salt cake." The latter is mixed with certain proportions of limestone and powdered coal, exposed to a strong heat in a furnace, and the result is the production of carbonate of soda, which is easily separated from the ash of the limestone and coal. The chlorine on being rejected by the sodium in the first process allies itself with the hydrogen of the vitriol, and forms hydrochloric acid, the fumes of which are of a most deadly character. For a considerable time the chemical manufacturers allowed this acid to escape into the air, with the result that over a wide area surrounding their works no vegetable life could exist. This was a constant source of complaint, and the Legislature had to step in and compel the proprietors to seek some means for the abatement of the evil. It was found that the objectionable vapours could be condensed in water, and appliances for so arresting it are now in general use. From the liquid thus obtained the chlorine is extracted by a simple operation, and combined with lime to form bleaching powder. But we need not go farther into detail on this branch of the subject.

If we allowed our piece of rock salt to share the fate of its fellow smaller fragments we should see it borne off and cast into one or other of a series of large open tanks or ponds which are an adjunct of each of the salteries. These tanks contain brine, and it is from that liquid that crystallised salt, for domestic, antiseptic, and other purposes, is made. The brine is formed by the solution of the rock salt in the water of springs or subterranean lakes; and the supply of it appears to be inexhaustible. In some parts the brine rises to the surface of the ground, but in others it has to be pumped from a depth of two hundred feet or more. The proportion of saline matter held in solution varies to some extent, but for the most part it constitutes 25 per cent. of the total weight of the brine, whereas the saltest sea-water obtainable contains only 3·56 per cent. On being drawn, the brine is allowed to flow into the reservoirs referred to, where evaporation goes on, to some extent, in a natural way. To strengthen the brine some of the rock salt is added, but usually not more than the fragments that occur in mining.

The salt is extracted from the brine by evaporating the latter by heat, until a point is reached at which the proportion of water is too small to hold the mineral in solution, and it becomes solidified in the form of crystals. The evaporating pans are huge trays of iron boiler-plate, and usually measure forty or fifty feet in length, by half that breadth, and fifteen or eighteen inches in depth. They are supported on brickwork in which furnaces and flues are constructed. The quality of salt to be produced is determined by the temperature at which evaporation is carried on. Bay or fishery salt, which is very coarse in the grain, is made at a temperature of 110°; what is known as "common salt" at 175°; and "stoved," or fine table salt, at 220°. It will be obvious from this that the finest quality is most rapidly precipitated, and it is usual to devote the pans to fishery salt on Sundays, so that a minimum of labour is required on that day. In the production

of two tons of common salt, one ton of coal is consumed; and a pan of average size is capable of turning out two hundred and fifty tons of that quality per week.

By stooping over the pan the process of crystallisation may be seen going on. It begins, as already stated, when the evaporation has proceeded so far that there is less water than is sufficient to hold the salt in solution. Little patches of what seems to be semi-transparent scum appear on the surface. These patches are composed of groups of salt crystals which are thus formed on the surface of the brine, and sink when they acquire a certain weight. The crystals are cubical in form; and when the evaporation is conducted rapidly, they arrange themselves in a peculiar way, and form conical or "hopper" crystals. The manner in which these are built up is shown in Fig. 2, where A represents the first-formed crystal floating in the brine, in which it

Fig. 2.—Formation of Salt Crystals.

makes a depression. Fresh crystals forming near are attracted to this centre, and attach themselves to it—first in one row, as in B, and so on, until the mass is completed, when it sinks to the bottom and makes way for fresh structures of the same kind. The crystals are allowed to accumulate until the solid matter in the pan is equal to about three-fourths of its contents. In the case of the table variety, the salt is ladled from the pan into wooden moulds, in which it is allowed to consolidate; and on removal from these, it is dried in a stove. The coarser salts are deposited on a platform and left to drain for some time, after which they are completely dried in the stove.

Owing to the dissolution of the rock caused by drawing off the brine, extensive subsidences of ground take place at intervals, whereby houses are wrecked, gas and water-pipes broken, railway and canal traffic interrupted, and patches of valuable land flooded. Loss of life has also been caused—the most serious about thirty years ago, when two cottages and an engine-house were swallowed up, and thirty persons perished. The wharfs on the Weaver have had to be raised repeatedly, and in the lower parts of Northwich houses and trees have sunk so far as to be surrounded by water. In the town itself it would be difficult to find a bit of wall true to the plummet, or a door or window exactly square. Walls are cracked and roofs "saddled" in every direction, and houses are pointed out which have been twice rebuilt within forty years, while others are miraculously held together by iron stays and other devices. Various plans have been tried to counteract the instability of the ground, the most successful being that according to which the houses rest at the street level on great beams of timber. These beams form, as it were, a second foundation for the houses; and whenever signs of subsidence appear, the introduction of fresh bricks or wedges between the beams and the masonry beneath them, keeps the upper part of the building from being wrecked. So serious is the effect of the repeated subsidences on property, that the owners have, on more than one occasion, appealed to the Government to step in and put a stop to the pumping of brine.

It but remains, ere finishing our chronicle of "A Piece of Rock Salt," to say a word on the antiseptic uses of salt—that is, its employment to prevent the decay of meat, fish, &c. A large quantity of the mineral is used in this way, especially in the "curing" of fish. When salt is applied to fresh meat or fish, the juice contained in these dissolves it and forms a brine, which is proof against the agents of putrefaction. It has also the power of preserving wood from dry-rot, and this quality has long been taken advantage of by ship-builders, who steep their timber in brine before incorporating it in the vessels. In cases where the wood has not been so treated, it is customary for ship-owners to take a salt cargo as early as possible after their vessels are launched.

In the beginning of the present century salt cost from £12 to £14 per ton; its price at present is barely a twentieth of the first-named sum. In Tibet and other parts of the world it is so valuable as to constitute almost a currency.

From the Cheshire field no less than two million tons are drawn annually; and for the transport of this several hundred vessels ply regularly on the Weaver. Some domestic salt is still obtained from the sea, but in this country that mode of obtaining it is almost extinct.

PROTECTIVE MIMICRY IN ANIMALS.

By Alfred Russel Wallace, F.L.S., Author of "The Malay Archipelago," etc.

IN a former article (pp. 128—137), on the "Protective Colours of Animals," we endeavoured to illustrate the purpose and origin of all those peculiarities of colouring which tend to conceal animals from their enemies or from the prey which they wish to capture; we showed how widespread were such colours in nature, and how often it happened that what seem showy colours when we examine the species in confinement, or when preserved in a museum, are really protective when the animal is seen in its native haunts and in the attitude it usually assumes when at rest. We referred to many cases of special imitation by insects of vegetable substances — of leaves or flowers, bark or moss—sometimes so wonderfully accurate as to deceive the eye of the experienced naturalist as well as that of the hungry bird. But besides all these, we called attention to a totally different kind of protection, always associated with conspicuous instead of protective colouring. A number of insects (and some of the higher animals) possess secretions which are so nauseous as to render them generally uneatable. This is a perfect protection against being devoured, but it would be no protection against being hunted, and caught, and often killed, if there was nothing to distinguish these from the great majority of eatable insects. But eatable insects (if soft and defenceless) are almost always protected by obscure or green tints harmonising with their surroundings. Evidently, therefore, the best way to distinguish the uneatable kinds would be that they should be of gay and brilliant tints, strongly contrasted with their surroundings, and readily distinguishable from a considerable distance. Marvellous to relate, this is actually the case; and the uneatable insects are, almost without exception, gaudily and conspicuously coloured. A number of such cases were adduced, especially among our native caterpillars, and proofs of their non-edibility were given.

We now propose to deal with this part of the subject more fully, in order to explain what is meant by "protective mimicry"—perhaps the most interesting and the most wonderful of all the phenomena of colour among animals. It is only among the teeming forms of life of tropical forests that the best cases of mimicry are to be met with, and we shall therefore now have to deal with objects for the most part unfamiliar to the British collector. We hope, however, by means of numerous illustrations, to make the subject intelligible to our readers, and especially to such as have some knowledge of our native insects.

Mimicry is the term applied to the phenomenon presented by certain species which, being themselves eatable, and belonging to groups which are attacked and devoured by numerous enemies, obtain protection by their close resemblance to some of the brightly coloured species which are free from attack on account of their nauseous odour or general inedibility. In most cases it is not a general but a special resemblance which serves this purpose, sometimes carried so far that the mode of flight and general habits are imitated, as well as colour and marking. The most numerous examples of mimicry occur among butterflies, but there are almost equally remarkable cases among beetles and other orders of insects, as well as a few among reptiles and birds. We will, therefore, first describe the groups of butterflies which are the subjects of mimicry by other groups.

In all tropical forests butterflies are abundant, and very varied in size, form, colouring, and mode of flight. Some fly with great rapidity, others have a zigzag, jerking mode of flight, and many such are adorned with brilliant colours. Great numbers of Satyridæ and Erycinidæ keep near the ground, with a slow hovering flight, and these have generally a sober style of coloration; while many of the showy species have their under-sides adorned with rich dark marblings, which render them inconspicuous as soon as they settle on a leaf or branch. But there are three great families—the Danaidæ, Heliconidæ, and Acræidæ—one or other of which is everywhere abundant both in species and individuals, and which are always remarkable, for their beauty or their conspicuousness; for their slow and lazy flight; for never trying to conceal themselves, and never flying high up in the air. The under-sides of their wings, too, are always coloured nearly the same as the upper, or, at all events, never present markings tending to concealment. These three families are closely allied to each other, and should, perhaps, form sub-divisions of one family, and they are believed to be most nearly related to the Nymphalidæ (to which family belong our tortoiseshells and fritillaries), of which they are a special development. They all have

the cell of the hind-wings closed, whereas in the Nymphalidæ it is always open; but they agree with the latter family in having the first pair of legs short and imperfect in both sexes, but more especially in the males, and in the pupæ being freely suspended by the tail.

All three groups have the peculiarity of possessing a powerful odour, which appears to pervade the whole body. When a specimen is caught and pinched between the fingers, a yellow fluid oozes out, which has a strange pungent smell and stains the skin. This has been observed with the Heliconidæ of South America, the Acræidæ of Africa, and the Danaidæ of Asia and Australia, and it appears to be of a very similar nature in all these groups. This pungent yellow secretion is very distasteful to birds and other insectivorous animals, so that the butterflies in question are never persecuted as others are. Some persons have doubted whether birds catch butterflies at all. Swallows, however, have been seen chasing white butterflies even in England; but in the tropics insectivorous birds belonging to many distinct families are much more numerous, and no eatable insects escape them. Mr. Belt, when in Brazil, watched a pair of puff-birds catching butterflies during half an hour, capturing many and carrying them to their young; but though numbers of Heliconidæ were flying slowly about, the birds neither noticed nor made any attempt to catch them. Neither Mr. Bates nor myself ever saw these butterflies attacked by birds, or lizards, or predacious insects, though they often rest exposed, hanging on the tips of leaves where they would be easily captured; and though the wings of butterflies that have been caught and eaten are often found lying in the forest paths, those of the Heliconidæ are never found among them. Dragon-flies were seen to catch Pieridæ in Natal, but never the slower-flying Acræidæ; while among the wings of butterflies found under certain trees where they assemble to feed on the exuding sap, and are captured by mantises and other insectivorous creatures, no Acræidæ or Danaidæ were ever found. We may consider it, therefore, to be an established fact that these three groups of butterflies enjoy almost perfect immunity from attack, owing to their offensive taste and odour; and their peculiarities of form and colour as well as their mode of flight, seem to be so well known to all insectivorous creatures, that they are recognised at a considerable distance, and thus not only escape being devoured, but are generally free from all pursuit or molestation. No doubt young birds or lizards sometimes make the trial, but the result is so disagreeable that they very soon learn what to avoid.

The peculiar odour is found in the caterpillar and the chrysalis of these butterflies, as well as in the perfect insects, and the result of this freedom from persecution is that they swarm in the forests to a greater extent than any other butterflies. The Heliconidæ of South America and the Danaidæ of the Malay Islands may always be found, even when other butterflies are very scarce, and there are many places where hardly any other kinds can be seen. It is evident, therefore, that if any other butterflies, belonging to eatable groups, should closely resemble any of these inhabiting the same districts, they would certainly be mistaken for them, and so obtain protection. Wherever these groups are found there are such cases of mimicry, of which we will now give some of the more interesting examples.

In tropical America the Heliconidæ* are immensely abundant, about 400 species having been described up to 1871, while, as many new ones are discovered every year, the number cannot be now much less than 500 species. They are also, as already stated, very abundant in individuals, and as all these are, without exception, uneatable, it is not surprising that insectivorous creatures have got to know them well and avoid them. They differ wonderfully among themselves in colour, some being black or blue, banded with yellow or white; others rich red, with yellow bands and rays; others rich brown and yellow spotted; while an immense number have transparent wings, either simply veined or delicately tinged with yellow, brown or purplish. Yet, amid all this variety, the general form, the style of marking, and the

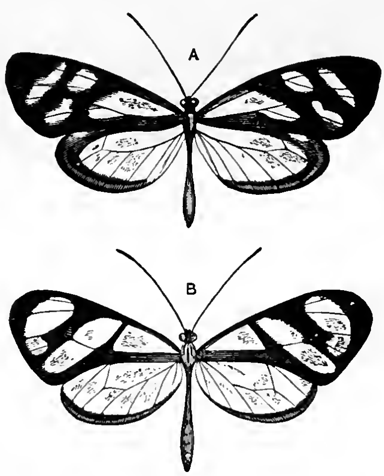


Fig. 1.—Leptalis theonoë (A); Ithomia flora (B).

* They have now been divided into two families, Heliconidæ and Danaidæ; but I keep the old nomenclature for simplicity.

mode of flight are so peculiar, that even species never seen before are recognised at a glance as belonging to this family.

In the same forests are found a considerable number of the totally distinct family of Pieridæ, to which belong our well-known "cabbage," "orange-tip," and "brimstone" butterflies. Most of these are white or yellow, variously marked and shaded, but still unmistakably Pieridæ; but there is one genus—*Leptalis*—which has more elongate wings than usual and a weaker flight, and these vary greatly in colour, some being white, others yellow or yellow and black, while others are coloured exactly like the Heliconidæ. The wonderful thing is, that the resemblance is not general but special. The coloured *Leptalis* does not look like a new species of Heliconidæ, but exactly imitates an existing species, and *always a species which inhabits the same locality*. Thus the transparent-winged, black-banded *Ithomia flora* (one of the Heliconidæ) is accompanied, at Cupari on the Tapajos river, by *Leptalis theonoë* (Fig. 1), which so closely resembles it that it cannot be distinguished when on the wing; while in other parts of the Amazon valley distinct species of *Ithomia*, with orange-red bands and spots, are imitated by varieties of this *Leptalis*. At Ega, on the Upper Amazon, the handsome brown-black and yellow-banded *Mechanitis obscura* (one of the Heliconidæ) is accompanied by *Leptalis Egaëna*, closely resembling it in size, colours, and markings, and both have long yellow antennæ (Fig. 2). Still more remarkable is the large and handsome yellow-and-black *Methone psidii* (one of the Heliconidæ), accompanied by *Leptalis orise*, equally large and very similarly marked and coloured; and in this case both have long black antennæ with a yellow club (Fig. 3).

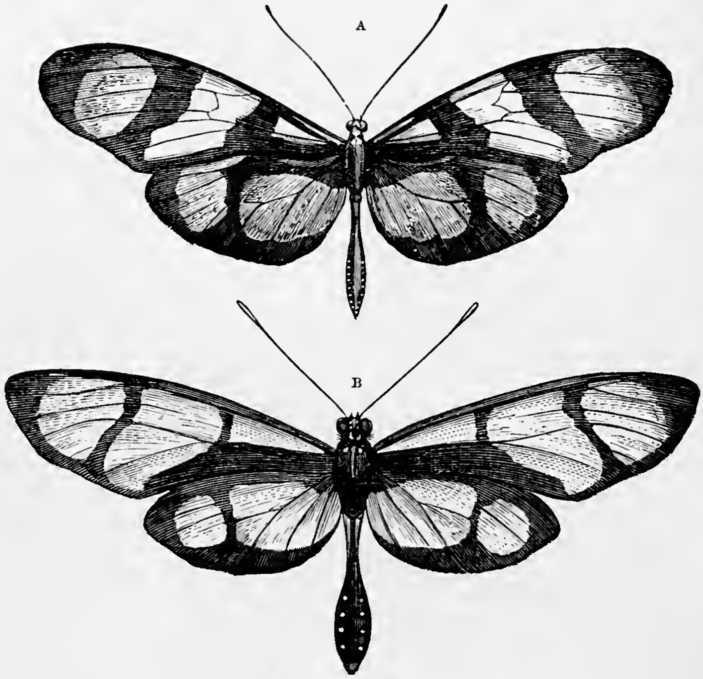


Fig. 3.—Leptalis orise (A); Methone psidii (B).

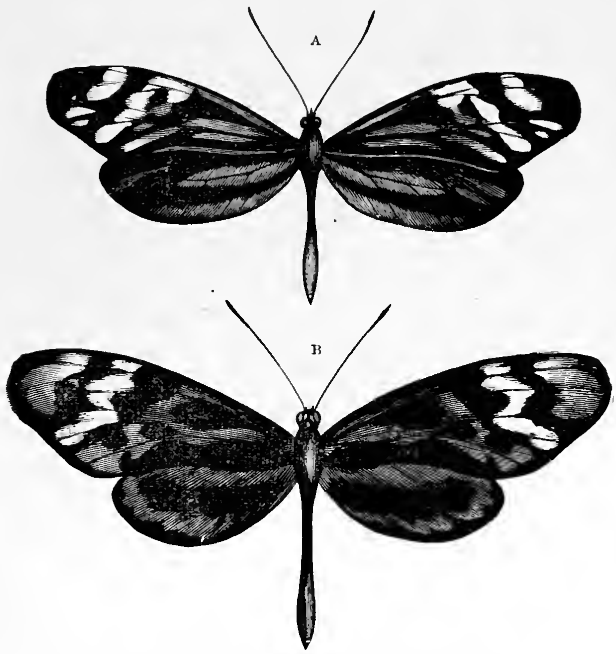


Fig. 2.—Leptalis Egaëna (A); Mechanitis obscura (B).

These are only a few out of many examples that might be referred to, but it is necessary to see the specimens themselves in order to appreciate the wonderful change that has taken place from the usual style of colouring of the Pieridæ (still prevalent even in the genus *Leptalis* itself) to these richly-coloured and strangely-marked forms. Before going further, however, it will be well to show how greatly the two groups, *Leptalis* and *Ithomia*, really differ. The accompanying figures (Fig. 4) show the anterior feet, the pupæ, and the larvæ of the two families Pieridæ and Heliconidæ. In the former the feet are long and perfect, with five-

jointed tarsi and bifid claws; the pupa is always supported by a looped thread, and the larva, or caterpillar, is smooth, slightly downy, but without spines or processes of any kind. In the latter the anterior legs are short and imperfect, having no tarsi in the male, and only one or two joints in the female; the pupa is always freely suspended, without any brace or loop, and the larvæ are always furnished with fleshy processes. These combined differences are so important that we may consider the two families to be at least as distinct as deer are from goats, or robins from finches.

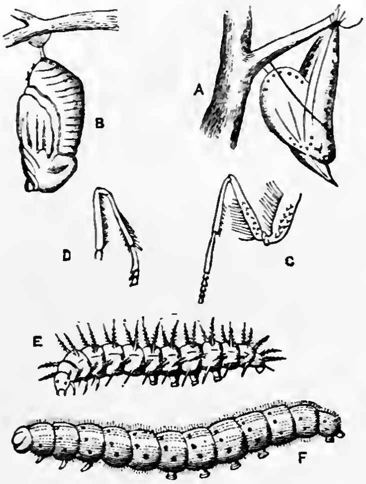


Fig. 4.—(A) Pupa of Gonepteryx Rhamni; (C) Leg of Gonepteryx; (B) Pupa of Danais plexippus; (D) Leg of Danais plexippus♀; (E) Larva of Acræa violæ; (F) Larva of Pontia brassicæ.

Besides the genus *Leptalis*, several other groups imitate the Heliconidæ in an equally extraordinary manner. A true Papilio (*P. pausanias*) has the exact colouring of *Heliconius clytia*—rich steel-blue with yellow bands; while another most remarkable species (*P. zagreus*) is richly marked with stripes and spots of yellow, brown, and black, so as closely to resemble the Heliconoid *Lycorea atergatis.* Two genera of Erycinidæ (*Ithomeis* and *Stalachtis*), and moths of the genera *Castnia*, *Dioptis*, and *Pericopis*, also resemble species of Heliconidæ in their respective districts in an equally remarkable manner.

In all, or almost all these cases, it has been observed that the mimicking species are much less plentiful than the Heliconidæ which they resemble; and a little consideration will show us that this is essential to the success of the imitation. For if the eatable Pieridæ and other groups were as abundant as the uneatable Heliconidæ, insectivorous animals would soon find it out, and would systematically capture them both, on the chance of getting at least one that they could eat for every one that they were obliged to reject. The fact seems to be, however, that the imitating species are usually very scarce indeed: often not one to a hundred, and sometimes not one to a thousand of the species they imitate; so that they are quite secure among the crowd of uneatable creatures so much resembling them. It may be asked, however, why, as they have the same protection, they do not increase and become nearly as numerous as the uneatable kinds. The answer is, undoubtedly, because their larvæ and pupæ are not protected, and thus suffer great destruction; and this was probably the reason why certain species acquired protection by mimicry in the perfect state as the only means of escaping impending extermination. It is evident that those species which had long and delicate wings and a slow flight, and which, owing to the thinning out of the larvæ and pupæ, were never very abundant, would be most liable to extermination. But these long-winged kinds would in form resemble the Heliconidæ, and any variations of colour tending to make them more like any of the species of that group would be an advantage. Such varieties would therefore have a better chance of escape, and in a long series of generations some of them might at least come to have the wonderful resemblances we now find, while many others, failing to vary sufficiently, have no doubt become extinct.

We will now pass to the African continent, where Acræidæ abound both in species and individuals, while Danaidæ, though few in species, are still sufficiently plentiful in individuals. These take the place of the Heliconidæ of South America, enjoying the same advantages; and they are mimicked in an equally remarkable manner by butterflies of three distinct families—Papilionidæ, Nymphalidæ, and Eurytelidæ; but not by any Pieridæ, which form the bulk of the mimicking species in South America. As an example we may take the *Acræa Euryta*, a common but remarkable butterfly of West Africa, numerous varieties (or allied species) of which are figured in Mr. Hewitson's "Exotic Butterflies," Vol. IV., Pl. IV., V. (Acræa); and in the same volume under Diadema (a genus of Nymphalidæ), Pl. III., are a series of insects, which it is hard to believe, at first sight, are not also varieties of the same species (Fig. 5). There is also a species of *Melanitis* (Fam. Eurytelidæ) that resembles the same species of *Acræa*. Another species, *Acræa zetes*, has a different style of marking, being red with numerous black spots, and this is very well imitated by another species of *Diadema* inhabiting the same districts.

But the most remarkable case known in Africa is presented by a true *Papilio* which, in several varieties and allied species, mimics the common *Danais echeria* with its varieties and allied species.

Danais Echeria (Fig. 7, A) is an elongate-winged black butterfly with a group of spots, either buff or

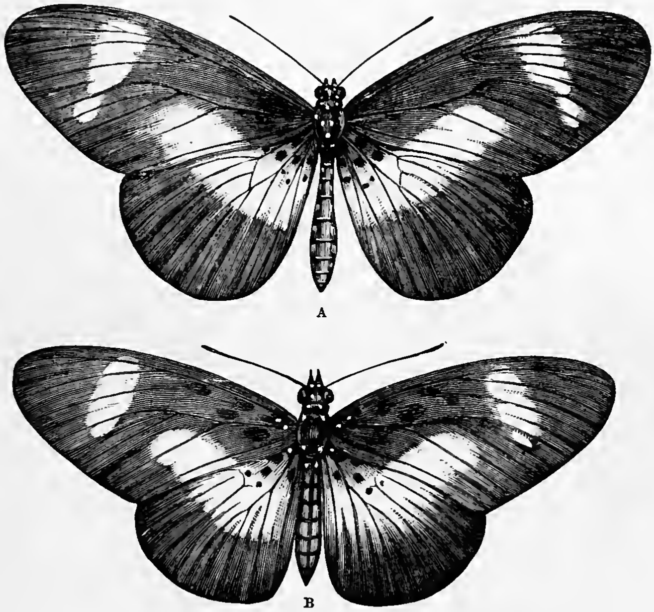


Fig. 5.—Acræa gea (A); Diadema Hirce (B).

white on the front wings, and a broad buff band across the hind wings; varying considerably in different parts of South Africa. Another species, *Danais niavius* (Fig. 8, A), is larger and handsomer, being deep black with two very large white patches, occupying more than half the surface of the wings. Yet another species, *Danais chrysippus*, perhaps the commonest of all, is rich orange-red, bordered with black on the hind wings, while nearly the outer half of the upper wings is black crossed by a broken band of pure white. These three butterflies may be said to be totally unlike each other in colour and markings, and each of them is accompanied by a Papilio closely imitating it, which have all been described as distinct species. A gentleman resident in Cape Town (Mr. Roland Trimen), who in 1861 published a book on the butterflies of South Africa, had his attention called to these cases of mimicry by the papers of Mr. Bates and myself, and especially to the fact that very often the females only have protective or imitative colours. He then observed that all these Papilios were, without exception, females, and no male specimen was to be found in any of the rich museums or private collections of this country. He also observed that wherever these butterflies were found, there was also found the large and handsome *Papilio merope* (Fig. 6), conspicuous by its pale sulphur-yellow colour, the anterior wings black bordered, while the tailed hind wings are crossed by a broken black band. This insect is as completely unlike all the others as possible; but it was always of the male sex, no female being known in any collections, and it was only found in districts where some one or other of the mimicking female Papilios were also found. The two sorts were also seen flying together and chasing each other, just as males and females of the same species often do; so, putting all these things together, he ventured to announce his belief that *all were one and the same species.*

On close examination it was found that there were many minute points of resemblance between these very different-looking insects, and a number of entomologists who were already acquainted with similar facts in other countries, concurred in Mr. Trimen's view. Others, however,

Fig. 6.—Papilio merope (*male*).

strongly opposed it, especially Mr. Hewitson, who possessed the finest collection of butterflies in England. When figuring some of these female Papilios in his work on "Exotic Butterflies,"

he wrote thus:—"That the butterflies now figured are all females, there cannot, I think, be a doubt; but that they are the females of *P. merope*, as suggested by Mr. Trimen, I do not for one moment believe." And he supported his disbelief by what is certainly a most remarkable fact, that in the adjacent island of Madagascar there is a slight variety of *Papilio merope*, which has a female almost exactly like itself, while nothing resembling the other females is found there.

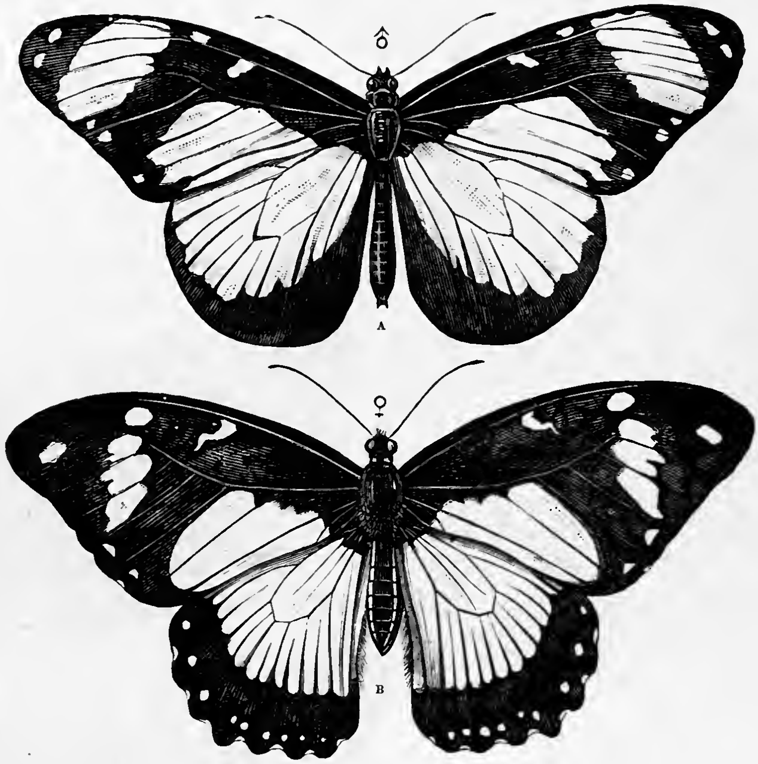


Fig. 8.—Danais niavius (A); Papilio merope ♀ (P. hippocoon [B]).

In order to settle the question, Mr. Trimen requested his friend Mr. Mansel Weale to endeavour to obtain the eggs or caterpillars of one of the disputed females, and raise therefrom the perfect insect. This was done. Mr. Weale found eggs and larvæ of *Papilio cenea* (which was the name hitherto given to the female which resembled *Danais echeria*), and succeeded in raising from them thirteen butterflies. Of these butterflies, seven were males—the well-known yellow-and-black tailed *Papilio merope*; four were buff-banded females, mimicking *Danais echeria* (Fig. 7); one was a black-and-white female like *Danais niavius* (Fig. 8); and one was a red-winged female like *Danais chrysippus*. Here was positive proof that all these strangely different butterflies are one and the same species, the females mimicking distinct species of Danais!

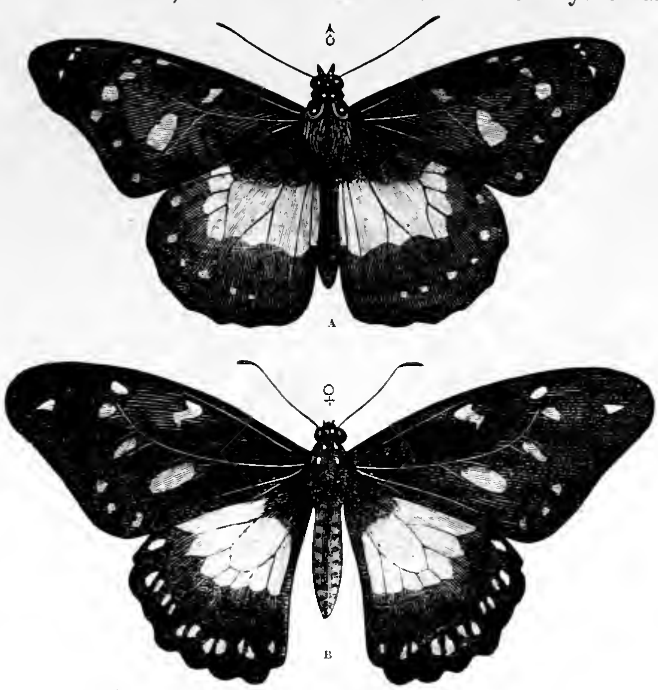


Fig. 7.—Danais echeria (A); Papilio merope ♀ (P. cenea).

There are several other interesting facts connected with this butterfly. The caterpillar is the exact colour of the leaves it feeds upon, and is thus protected; the chrysalis is of a remarkable, broad shape, so as exactly to resemble a leaflet of the same plant, and the under side of the male butterfly is of mottled brown tints, and when at rest closely resembles a dead leaf. The perfect male is subject to the attacks of birds, since Mr. Weale saw one actually captured by a large crested fly-catcher; but they fly strongly, darting up and down with great rapidity, and thus no doubt many escape. The flight of the females is, on the other hand, heavy and

slow, and while laying their eggs on the proper food-plant they are especially subject to attack. We may well suppose, then, that they were once near extermination, when some ancestral form varied sufficiently to become something like one of the Danaidæ, and thus obtained the protection necessary for the preservation of the race. Why the Madagascar form of the species did not produce similarly diverse females is not quite clear; but it is certain that in such islands as this, where the number of species both of birds and insects is much less than on continents, the struggle for existence is not nearly so severe. Forests also are denser and more extensive in Madagascar, and thus offer better concealment for insects, which, therefore, may not need the same amount of extraneous protection as on the continent. Having devoted so much space to *Papilio merope*, we must pass by the many other cases of mimicry that occur in Africa, in order to notice a few of those of India and the Malay Archipelago.

In these countries three genera of Danaidæ, *Danais*, *Euplœa*, and *Idea*, are very abundant, each having a peculiar style of colouring. *Danais* has elongate wings, and is very varied in colour, but is often semi-transparent greenish or bluish-white with black stripes, and often suffused with yellow or brown. *Euplœa* has more rounded wings, and is usually dark coloured, with white bands or spots, but is often richly glossed with metallic blue, and very handsome. *Idea* is very large, with thin papery wings of a whitish semi-transparent colour, marked with round spots or with bands of black. All these forms are closely imitated by various species of *Papilio* and *Diadema*, of which only a few of the more remarkable can be here noticed.

One of the most common Danaidæ in Malacca and Borneo is *Euplœa midamus* (Fig. 10), the male of which has the fore wings of a brilliant metallic blue, with faint bluish-white spots, while the hind wings are uniform brownish black. The female differs considerably, the hind wings being covered with narrow white lines radiating from the body, and having a marginal row of white spots. This is exactly imitated in the two sexes of *Papilio paradoxa* (Fig. 9), which inhabits the very same districts, but is, comparatively, rare; but the two species are so much alike that I could hardly ever distinguish them when on the wing. The almost equally common *Euplœa rhadamanthus* is very distinctly coloured, with sharply defined white patches and blue spots on a black ground, very unlike any other butterfly except the *Papilio caunus*, which imitates

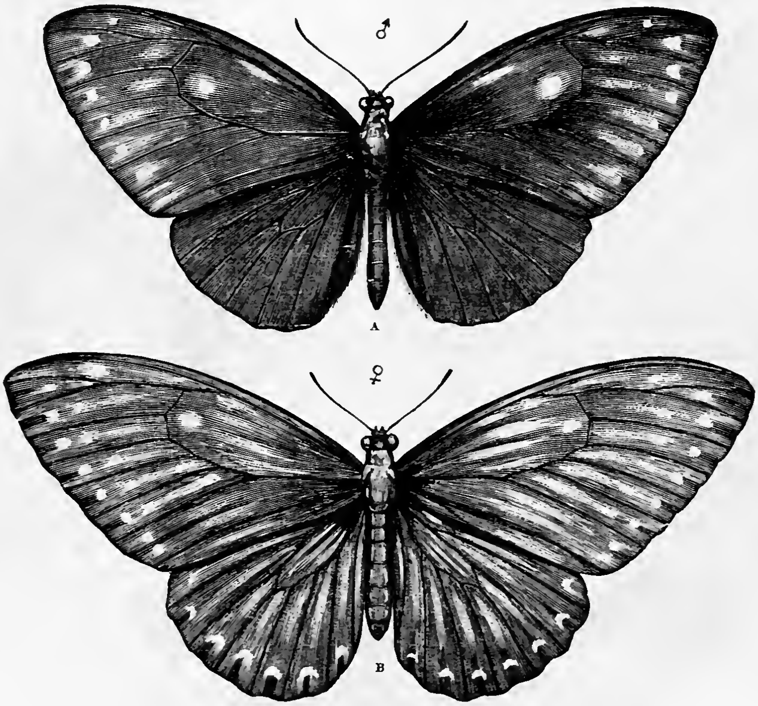


Fig. 9.—Papilio paradoxa: *male* (A), and *female* (B).

it with wonderful accuracy both in markings and in mode of flight. In the Philippine Islands the large white-and-black *Idea leuconoe* is closely imitated by the fine *Papilio idæoides* of the same islands.

We have here also two examples of female butterflies being modified for protection, so as to be quite unlike their males. The male of the very common *Diadema misippus* (Fig. 11) is black, with four conspicuous oval white spots margined with glossy blue. The female is a totally different-looking insect, of a rich orange-brown colour, margined with black and white, and with a white band crossing the black apex of the anterior wings. The idea of their being two sexes of the same species would never strike any one, and would seem utterly preposterous if it were told them for the first time. It is, however, undoubtedly the fact, and the female is an

accurate mimic of the excessively common *Danais chrysippus*. The male *Diadema misippus* flies rapidly, and often mounts into the air, while the female flies slowly and keeps low down; and as the species frequents open grounds rather than forests, she would be in great danger of extermination while hovering over the plants on which she lays her eggs, and thus has great need for the protection gained by her resemblance to the uneatable *Danais chrysippus* which swarms everywhere (Fig. 11).

Fig. 10.—Euplœa midamus: *male* (A), and *female* (B).

The other case is that of a *Diadema* from the larger Malay islands, which, owing to its rich metallic blue gloss, had been described, thirty years ago, as the male of another species. On close examination, however, I found it to be a female, while the male is a comparatively dull insect, with hardly any blue gloss and much whiter spots. The two differ, in fact, just as do the sexes of many butterflies, but in a reverse way, the female being here the more brilliant, the male far less so, for which reason I named the species *Diadema anomala*. The explanation of the anomaly is, that the female mimics the male *Euplœa midamus* with great accuracy, and thereby acquires the protection which her slow flight and exposure while egg-laying renders necessary. This is a most interesting case, as proving the great power of the need of protection to lead to modifications of colour in the female sex. For purposes of concealment, females generally have less conspicuous tints than their mates, but when protection can be more readily secured by resemblance to species absolutely free from molestation, they can acquire distinct or even brilliant colours, and such as are generally characteristic of the male sex.

Cases of true mimicry among Lepidoptera, such as we have here described, are almost unknown in temperate lands, where the forms of insect life are so much less varied; but there is one very good case in temperate North America, and there are also a few in our own country. In the United States the handsome red-and-black *Danais erippus* is very common, and there occurs with it one of the Nymphalidæ, *Limenitis archippus*, which closely resembles it in colour and markings, and is totally unlike all the other species of its own genus. The white moth, *Spilosoma menthrasti*, mentioned in our former paper as being uneatable, is very abundant; but there is another moth, *Diaphora mendica*, of which the female only is white, which appears at the same time of the year, and is much less common, so that it is very probable that this species is secure from enemies by being mistaken for the uneatable kind. Our clear-wing moths of the families Sesiidæ and Ægeriidæ are, however, undoubted mimickers, many of the species resembling bees, wasps, or ichneumons, as their names imply. *Sphecia crabroniformis*, for example, imitates the wasp, *Odynerus antilope* (Fig. 12); and the common little currant moth, *Trochilium tipuliforme*, resembles a small black wasp, *Odynerus sinuatus*, which is abundant in gardens at the same season.

Coming to the order Coleoptera, or beetles, we find numerous cases of the mimicry of protected

by defenceless species. Some extensive groups have an offensive taste like that of the Danaidæ

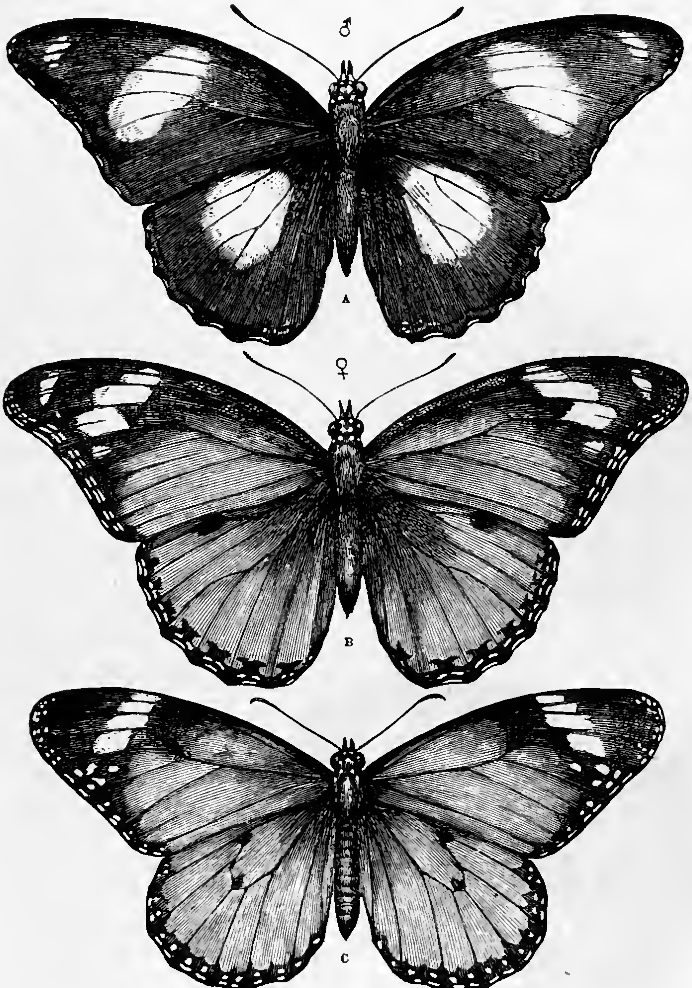


Fig. 11.—Diadema misippus: *male* (A), and *female* (B); Danais chrysippus (C).

among butterflies. Such are the Eumorphidæ and Hispidæ, and especially many of the Malacoderms, our own red-and-black species of *Telephorus*, commonly called "soldiers and sailors," being refused by most, if not all, birds. These groups

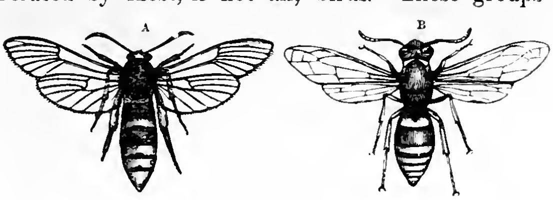


Fig. 12.—Sphecia crabroniformis (A); Odynerus antilope (B).

have all conspicuous colours and fly slowly, and many of the species are mimicked by Longicorns, a group of beetles which seems to be particularly subject to the attacks of insectivorous creatures, since a large number of the species have acquired protection, either by their colours, markings, and rugosities, causing them to resemble bark or foliage, or by their habits of concealment, feigning death, or feeding at night. Another group of beetles are protected by the excessive hardness of their integuments, which render them uneatable to most insectivorous birds. Such are many of the Curculionidæ and Anthribidæ, and both these groups are often mimicked by Longicorns in a most perfect manner. The most curious example is, perhaps, that of the Longicorns—*Doliops curculionides* and *D. geometrica* of the Philippines, which, both in shape and colours, closely resemble weevils of the genus *Pachyrhynchus*, peculiar to the same islands. This is the more remarkable, because the insects imitated are marked in a most unusual manner with geometrical patterns, and possess the most brilliant metallic colours. The Eastern tiger-beetles of the genera *Collyris* and *Therates* are also mimicked, the former by a Longicorn, *Collyrodes Lacordairei*, the latter by a species of Heteromera, and in both cases the imitation is very exact.

The same group—Longicorns—also mimic many other insects which it is to their advantage to be mistaken for. Different species resemble bees, wasps both blue and yellow, saw-flies, ants, and the strong-smelling Hemiptera. Our illustration (Fig. 13) represents one of these beetles, which exactly resembles a large blue wasp, both inhabiting the same districts in South America. The reason why cases of mimicry occur so much more frequently in this family of beetles than in any other, is, probably, because their enormous numbers and endless modifications of form and structure offer facilities for natural selection to work upon, some of them more or less closely approximating to the form and colouring of every other family of the order.

There are also many cases in which distinct orders of insects mimic each other. Moths which imitate bees and wasps have already been mentioned. In the Philippine Islands two very singular cases occur. An insect of the cricket family (*Condylodera*

tricondyloides) is so exactly like a tiger-beetle of the genus *Tricondyla*, that so old and learned an entomologist as Professor Westwood placed it among them in his cabinet, and kept it there for a long time before he found out his mistake. An-

Fig. 13.—Sphecomorpha chalybea.

other species of the same cricket family (*Scepastus pachyrhynchoides*) mimics a species of Pachyrhynchus (*P. venustus*), a beetle as totally unlike a *Tricondyla* as it is possible to find.

We cannot now do more than refer to the numbers of two-winged flies which mimic bees and wasps,* or the spiders which resemble ants; but we must just mention the Mantis which Mr. Bates found on the banks of the Amazon exactly resembling the white ants it feeds upon, and the crickets of the genus *Scaphura*, which accurately mimicked sand-wasps, the reason being that the sand-wasps are especially fond of crickets with which to provision their nests. These defenceless creatures have, therefore, in many distant countries, been preserved, by acquiring the form and colouring of stinging Hymenoptera, carnivorous Cicindelidæ, or hard-shelled Curculionidæ.

Owing to the comparative stability of the external form of the higher animals, and the important outward differences between the various groups, the facilities for the production of mimicry rarely exist in their case. Yet there are a few undoubted examples of very great interest. The chief venomous snakes of America belong to the Crotalidæ or "Pit-vipers" (of which the rattlesnake is the most remarkable), and are known by their broad and almost triangular heads; but there is one genus of poisonous snakes in America—*Elaps*, which belongs to a totally distinct family, and has a small oval head just like many harmless snakes. These, therefore, would be attacked and occasionally killed by snake-eating birds and quadrupeds, unless they had some distinctive mark as a notice of their possessing poison-fangs; and they have got this mark in a peculiar style of colouring different from that of any other snakes. They are all coloured with alternate black, red, or yellow rings from head to tail, giving them a most elegant and altogether peculiar appearance—a distinctive livery pointing them out as uneatable, in the same way that the Heliconidæ are pointed out amid the host of eatable South American butterflies. Now, just as the eatable and defenceless butterflies of the genera *Leptalis* and *Stalachtis* have taken on the livery of the Heliconidæ as a protection, so there are two or three genera of harmless snakes which have taken on the peculiar livery of those poisonous snakes, at least seven or eight species being known, each accurately mimicking in different parts of the

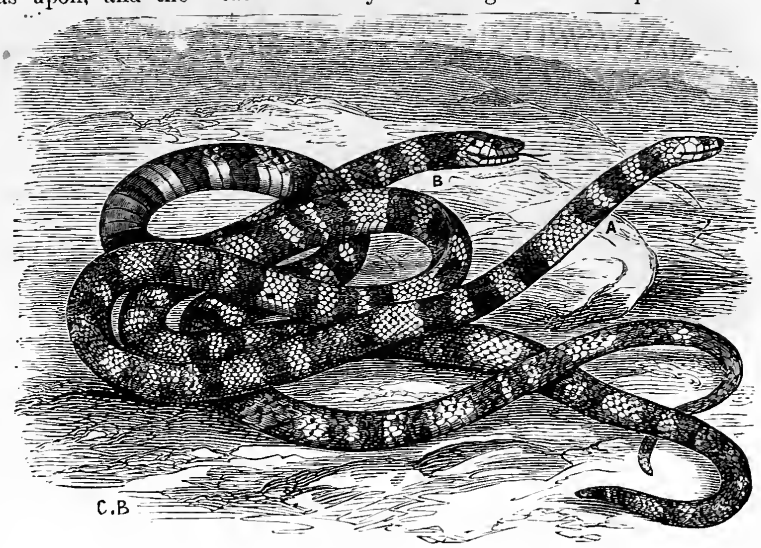


Fig. 14.—Elaps lemniscatus (A); Pliocercus elapoides (B).

country the particular species of Elaps found there. As an example we may name the deadly *Elaps*

* This is often so remarkable as to deceive the best observers. One of our first entomologists, Mr. McLachlan, informs me that once when out with a party of collectors he captured what he took to be a pair of humble-bees, and gave them to the late Mr. Frederick Smith, the greatest authority on bees, who carefully secured them in his collecting-box; and it was only on reaching home and proceeding to set them out that he discovered that they were not bees at all, but flies of the genus Volucella, which are parasitic on humble-bees, and are thus disguised in order that they may enter their nests with impunity in order to deposit their eggs.

lemniscatus, of Mexico, which has broad black bands on a red ground, each band divided into three parts by narrow yellow rings; and this very peculiar colouring is exactly copied in the harmless *Pliocercus elapoides* of the same country (Fig. 14). We can hardly have more wonderful and more conclusive cases of warning colour and protective mimicry than are afforded by these various species of American snakes.

Birds offer a few undoubted cases of mimicry, the most perfect being that of some species of *Mimeta*, a genus of brown orioles, which mimic *Philedon*, a genus of honeysuckers (Fig. 15). The latter birds, it may be remarked, are the largest of their family, and are very noisy and pugnacious; they are also very plentiful, and will band together to drive away crows and even hawks that intrude among them. We may presume, therefore, that they are generally unmolested, and it would thus be of use to any weaker bird to be mistaken for them. The orioles, though nearly as large, are decidedly weaker birds, and are far less numerous, and thus correspond to the general character of mimicking species. In the island of Bouru, one of the Moluccas, there is a peculiar species of *Philedon* (*P. bouruensis*), and in the same island a peculiar species of *Mimeta* (*M. bouruensis*), which are so much alike that in a great French work, the "Voyage de L'Astrolabe," the oriole is figured and described as a honeysucker under the name of *Philedon bouruensis!* the two birds belonging to families at least as distinct as thrushes and crows. The manner in which the imitation is effected is very curious. The *Philedon bouruensis*, as in almost all the species of the genus, has a large bare patch of black skin round the eyes; this is copied in the *Mimeta bouruensis* by a patch of black feathers. The narrow scale-like feathers on the crown of the *Philedon* are imitated by a dark line on the broader feathers of the *Mimeta*. On the neck of the *Philedon* the feathers are recurved, showing their pale under-surfaces and forming a kind of ruff or cowl which has given to them the name of friar-birds, and this is represented by a pale band in the *Mimeta;* and lastly, the bill of the *Philedon* has a protuberant keel at the base, and the *Mimeta* has the same character, though it is not found in the allied species. The colours of this pair of birds are simply brown, darker above and lighter below; but in the adjacent island of Ceram there is another species, *Philedon subcornutus*, which has a great deal of ochre-yellow in its plumage, and this is exactly imitated by the corresponding *Mimeta forsteni*, both being confined to this single island. If it could be thought that the resemblance in the one case might be accidental, and that their occurring in the same island was also a coincidence, the occurrence of another pair in another island renders this explanation inadmissible; but to any one who has comprehended the general principles of mimicry already set forth, it will be clear, that these are of exactly the same nature in the case of these birds, and can be explained only in the same way.

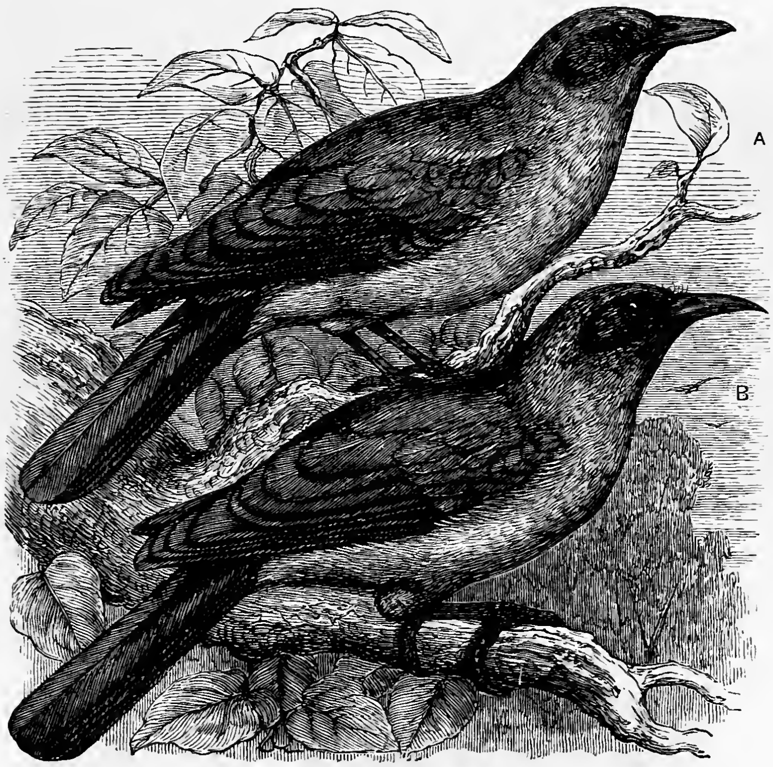


Fig. 15.—Mimeta bouruensis (A); Philedon bouruensis (B).

The family of birds which presents the greatest number of cases of mimicry is undoubtedly that of the cuckoos, the reason being that the species are

all of very weak structure and utterly defenceless. Many of the true cuckoos are coloured exactly like hawks, and this is particularly the case with those of the genus Hierococcyx, which are named hawk-cuckoos. Dr. Jerdon states that *H. varius*, a common Indian species, undergoes changes of plumage exactly corresponding to that of an Indian sparrow-hawk, *Micronisus badius*, and that it is often mistaken for that species by other birds. Another Indian cuckoo (*Surniculus dicrurioides*) is black with a deeply-forked tail, and is so exactly like the common King-crow (*Dicrurus macrocercus*) as to be mistaken for it. It is believed that it lays its eggs in the nest of the latter bird, and that this is the reason of its remarkably perfect mimicry; but no doubt it is also thereby protected from the attacks of hawks, as the king-crows are very pugnacious and aggressive birds, which attack and drive away hawks, kites, and crows, a habit from which they have obtained their popular name. In Sumatra and Bornĕo there is a large ground cuckoo (*Carpococcyx radiatus*) handsomely coloured with metallic purple and red, so as to resemble the pheasants of the country of the genus *Euplocamus.*

Among mammalia there are hardly any examples of one species imitating another of a different group for the purpose of protection, the best perhaps being the curious insectivorous Tupaias of the Malay countries, which almost exactly resemble squirrels both in their colours and their bushy tails, but which belong to a totally distinct order. If this resemblance is not accidental it must be for the purpose of enabling them to approach their insect prey under the guise of harmless squirrels. Another case is that of the Aard-wolf (*Proteles*), which has weak jaws, and feeds on white ants and carrion, but which is coloured and spotted exactly like the savage hyæna; and it may avoid the attacks of the more powerful carnivora, owing to the very general fear of the terrific bite of the animal it resembles.

In describing the phenomena of mimicry it is difficult to avoid conveying the impression, that there is some voluntary action in the creatures that thus seem to disguise themselves in order to be mistaken for quite different creatures; but those who have understood the explanation given in our former paper, of the mode in which ordinary protective resemblances have been brought about, will not fall into this mistake. If an Arctic bird has become white, and a forest bird green; if one insect is coloured like a leaf, another like the bark it clings to, we can easily see that it is only a step further in the same process for one insect to become exactly like another insect.

Some persons, however, have objected, that so many steps are required in the process of making a white *Leptalis* resemble a highly coloured *Ithomia*, that the chances against the necessary variations occurring are infinite. It is forgotten, however, that both the groups to which these genera belong have been undergoing constant changes for countless generations. Many Pieridæ have dusky, or yellow, or red markings, and many Heliconidæ have comparatively little colouring; and if we go back to the remote epoch when the Heliconidæ and Pieridæ were both much nearer to their common lepidopterous ancestor, we can have no difficulty in believing that species of one family might sometimes not be very unlike species of the other family. Now if at this remote period the Heliconidæ began to acquire the peculiar nauseous secretion which became a protection to them, and allowed them to increase and vary greatly, and to acquire the brilliancy of colour, length of wings, and slowness of flight which now distinguish them, it is not improbable that here and there one of the Pieridæ should be sufficiently like them to be mistaken for one of the group, and thus acquire a partial protection. This protection would inevitably increase by the simple action of natural selection, those variations of the ancestral *Leptalis* or *Euterpe* having the advantage which followed the variations of the ancestral *Ithomia* or *Mechanitis*, and thus, in the course of thousands or perhaps millions of generations, that close resemblance which we now see would be brought about. It must be remembered too, that the imitation would be rendered more accurate as time went on, owing to the increased acuteness of the insectivorous enemies of the butterflies. An imperfect resemblance would, after a time, be found out, and this would lead to the selection and perpetuation of more and more perfect mimicry. It may be asked, how do so many species of *Leptalis* still survive, which are yellow and white and not at all like Heliconidæ? and we can only give a guess in reply. Many of them are more rapid fliers; some may have different habits, and in some the larvæ may have better means of concealment and protection. As Mr. Darwin has remarked, we can seldom say why one of our native insects should be very common while another is very rare, and to answer similar questions regarding tropical insects is, of course, impossible. Our ignorance in this respect does not, however, prevent us from acquiring knowledge in other directions, and does not in the least affect the

extraordinary facts of mimicry, only a small selection of which have here been laid before our readers. These facts are so varied and so extraordinary, they occur in so many distinct groups of animals, and in so many different parts of the world, and they have been so carefully studied by several good observers, that not a doubt remains as to their reality; while no theory but that of Natural Selection affords—in my opinion—any intelligible explanation of them.

THE PHYSICS OF MUSIC.

By Professor F. R. Eaton Lowe.

THERE are few ears anatomically perfect that are altogether insensible to the charms of music. Its power to soothe or to excite, to soften and to refine, to move to sadness or to rouse to passion, is no mere visionary sentiment conjured up by poets and musicians, but an actual potential influence, which has been felt and appreciated by mankind from time immemorial. As education advances, music becomes more generally regarded as an essential and integral part of it, and the "concourse of sweet sounds," from being a source of mere sensuous enjoyment, becomes a subject of intellectual study. It is the cultivated musician alone, however, who can extract from music all the enjoyment it is capable of affording.

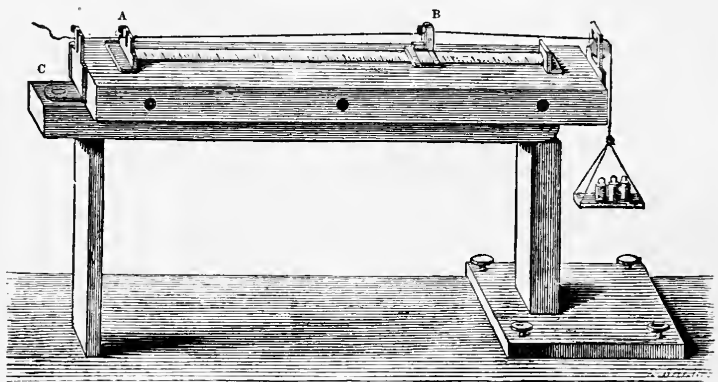


Fig. 2.—The Sonometer.

His disciplined ear alone can unravel the intricacies of the combined counterpoints, appreciate fully the resolution of chords, comprehend the working out of a theme, or detect the unity of idea pervading an entire composition. But it is reserved for the physicist to explain to the musician the various phenomena which accompany the production of those sounds with which he is so much enraptured; and the admiration which he feels for his favourite art cannot but be heightened by the knowledge thus acquired of the physical laws which operate in its exercise and development.

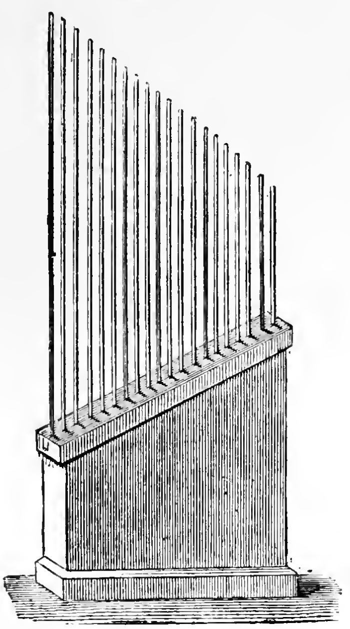


Fig. 1.—Marloye's Harp of Wooden Rods.

The general laws relating to the propagation of sound through air have already been discussed in these pages (Vol. I., p. 124), so that, in this paper, we shall confine ourselves to the consideration of those vibrations which, simply or compounded, are concerned in the production of those multifarious acoustic effects included under the general term *music*.

Musical sounds are produced by the vibration of strings or wires, in a state of tension, of rods of metal or wood, metallic plates or tongues, and by air-pulsations within tubes or pipes; thus we have stringed instruments, as the harp, violin, and piano; wind instruments, as the organ, trumpet, and cornet; reed instruments, in which a peculiar quality is imparted to the sound by the vibration of narrow slips or tongues of metal, as the oboe, bassoon, harmonium, and the reed pipes of organs; and, lastly, instruments of a more primitive character, in which solid rods or plates—either of metal or wood—are

employed, as cymbals, triangles, Marloye's harp (Fig. 1), and the *claquebois* of the French, which, constructed of glass or metal instead of wood, is here known as the harmonica.

We will first examine the phenomena attending the vibration of strings or wires. Such vibrations are most readily investigated by means of an instrument called a *sonometer*, or monochord. It consists simply of a string of catgut attached to a fixed point, carried over a pulley, and stretched by a weight at the other end (Fig. 2). Under the string is the sound-board C, which is a hollow box carrying the pulley and two bridges A and B, the latter of which alone is capable of a sliding motion, by which its position can be altered at pleasure. The string rests upon the two bridges, and it is evident that, by sliding the bridge B to or from A, we lengthen or shorten the vibrating part of it, and thus obtain a note of any desired pitch, in the same way as by altering the length of a trombone or an organ pipe. The tension of the string can be regulated by a proper adjustment of the weights by which it is stretched. The sound-board is an important part of the apparatus; for, without it, no musical sound would be emitted by the string when set in vibration, as the amount of motion communicated to the air by this means alone is too small to produce sonorous waves. But the hollow box takes up the vibrations of the wire, and, by means of its larger surface, they become intensified, so that the effect upon the surrounding air is vastly increased. To show that no musical sound, but simply a vibratory hum, is elicited from a string or wire dissociated from the sound-board, we have only to stretch such a wire upon two uprights connected by a cross-piece (Fig. 3) and to set it in motion

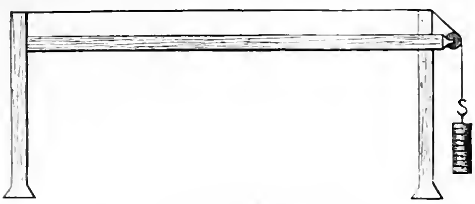


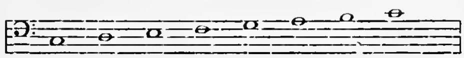
Fig. 3.—The Non-Musical String.

either with the finger and thumb or with a violin bow. The practical application of the sound-board to stringed instruments has been known for ages, although the principle upon which its action depended was not understood till acoustics developed itself as a branch of physical science.

Without its sound-board, the harp would be silent; and the violin, without its hollow case of perfectly elastic and well-seasoned wood, would be incapable of rendering audible those wonderful graduations of tone which distinguish it from all other instruments. The resonant effect of elasticity in the wood of the sound-board is best exemplified by the comparison between an old violin and a new one, or one in which the wood is tenacious and unyielding. The one may be cheap at a hundred guineas, while the other may be almost worthless except as a toy. The violin may be regarded as a sonometer with four strings instead of one, stretched by pegs in the place of weights to any required degree of tension. The bow used to set the strings in vibration is rubbed with resin to increase its purchase or hold upon their fibres, and thus to produce a more perfect excitation. Wires are capable of vibrating in two directions—longitudinally and transversely. The first kind of vibration takes place when a wire is rubbed in the direction of its length, but it is infinitesimally small when compared with the transverse, or the vibration from side to side; and this, then, we shall proceed to consider.

When the wire of the sonometer is drawn aside or plucked at its middle point and released, it commences a series of oscillations, its excursions on each side of the position of rest being performed, as in the case of the pendulum, in the same time irrespective of distance: for the greater the distance to which the wire is drawn from its horizontal position, the greater will be the force impelling it, and the more rapid will be its vibration. The arcs gradually become smaller, the oscillations less rapid, and, ultimately, friction and gravity combine to bring the wire to rest. When a wire is made to vibrate, as a whole, in the way just described, the sound it emits is its lowest or fundamental tone. Now let the movable bridge of the monochord be moved nearer the fixed bridge, till it stands under the middle point of the wire. This point can at once be determined by reference to the scale engraved on the upper surface of the sound-board. The scale is graduated into a hundred parts, so that the bridge in our present experiment stands at 50. On agitating the wire, we shall find that the note it emits is no longer the same, but the *octave* of the fundamental. The wire now vibrates twice as quickly as it did before; so that the proportion between the rates of vibration, a note and its octave, is as 1 to 2. Again, move the bridge towards A till it stands at 33, or one-third of the original length of the wire. The note it now gives is of a still higher pitch than before; it

is the fifth above the octave, or the twelfth above the fundamental, and thus, by continually shortening the string, we obtain notes that become proportionately more acute, till at length they become too shrill to enable us to attach to them any precise musical value. In the same manner, by proceeding in the other direction and lengthening the string, the rapidity of the vibrations is diminished, and the notes emitted become gradually graver, till they are no longer appreciable as music. By moving the sliding bridge to different points between those which yield the fundamental and its octave—that is to say, between 1 and 50—we shall discover the lengths of the string which emit all the notes of the diatonic scale. These lengths are indicated by the fractions placed below the respective notes, as follows :—



C	D	E	F	G	A	B	C
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

The length of string necessary to produce the fundamental or primary note C is here assumed to be 1. The length required to yield the note D will then be $\frac{8}{9}$ of this distance, and so on. But we have seen that when a string is halved, the rate of its vibration is doubled : so that if we wish to show the comparative rates of vibrations producing the notes of the gamut, we must reverse the above fractions, thus :—

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

The number of vibrations, therefore, necessary to produce D is $\frac{9}{8}$ of that necessary to produce C, and so on. This rule is usually stated thus :—*The rate of vibrations is inversely proportional to the length of the vibrating body.* In the piano, instead of one wire being employed to produce different notes by variation in its length, a number of wires are so arranged, that their lengths are proportioned to the above series of ratios. This, however, is on the assumption that all the wires are of equal thickness and density, and all pulled with equal tension. The thicker the wire, the lower is its rate of vibration ; and, consequently, the lower its pitch. The lower wires of the piano are not only thicker than the upper, but their diameter is practically increased by being bound round with copper, and thus, shorter wires than would be otherwise necessary can be employed for the bass notes. In this way we arrive at the following law :—*The rate of vibration is inversely proportional to the diameter.* Two more elements remain to be taken into account before we can determine all the conditions under which a string vibrates. These are *tension* and *density.* The greater the force employed to stretch the string, the greater will be the rapidity of its vibrations ; in other words, *the rate of vibration is directly proportional to the square root of the stretching weight.* Suppose, for example, a wire, when stretched by a weight of 1 lb., vibrates 200 times in a second, then we can cause it to execute 400 vibrations in the same time by applying a weight of 4 lbs., or treble the number—that is, 600 vibrations—by a weight of 9 lbs. Lastly, *the rate of vibration is inversely proportional to the square root of the density.* Two wires may have the same length, thickness, and tension, but unless their density be equal—that is to say, unless they have exactly the same amount of matter in the same bulk—there will be a variation in their rates of vibration, and, consequently, a difference in their musical pitch. Wires of platinum, copper, and iron of the same length and thickness would have different weights, their specific gravities being respectively 21·5, 8·9, and 7·8. The iron wire, stretched by the same weight would, therefore, vibrate more rapidly than the copper wire, and this again, much more rapidly than the platinum. The first of these four laws will apply equally well to vibrating columns of air enclosed within tubes, as an organ pipe, trumpet, or trombone. The longer the tube, the deeper is its musical pitch. Thus it is that, in the Pandean pipes, and in each stop of the organ, we observe the sounding-tubes arranged in a regularly diminishing series, terminating at the treble end in pipes only two or three inches in length, and less than half an inch in bore. In some of our great organs, as those of the Albert Hall, the Alexandra Palace, and St. George's Hall, Liverpool, the gravest sounds are produced by pedal pipes thirty-two feet long. These pipes excite about sixteen vibrations per second, while the shrillest in the treble produce 3,520 vibrations in the same time. These numbers, then, represent the complete range of vibrations corresponding to the full musical compass of seven octaves. But the human ear is capable of perceiving sounds much more acute than any we can elicit from musical instruments. Many sounds, so shrill as to be produced by 38,000 or 40,000 vibrations per second, are, to most ears, perfectly audible. It must be remembered, however, that the limit of susceptibility in the human ear

varies, like the power of vision, in different individuals. Sounds which are either too grave or too acute to be heard by some persons, are distinctly audible to others. As each octave is produced by twice as many vibrations as the one immediately below it, we shall find by continuing the geometrical series, commencing at sixteen and continually doubling, that we shall get a range of rather more than eleven octaves, thus:—

16	32	64	128	256	512	1,024
	1	2	3	4	5	6
2,048	4,096	8,192	16,384	32,768		
7	8	9	10	11		

This range of power in the organ of hearing is vastly greater than that possessed by the eye. Our power of vision is limited to a range of one octave only—that is to say, from the red end of the spectrum to the violet. We know that the spectrum is continued beyond these points in each direction, but that the eye is not sufficiently sensitive to render visible the rays which are above or below a certain degree of refrangibility. An ingenious little instrument, called the Galton whistle, furnishes a good acoustic gauge, by which the degree of sensibility in the ear to very acute sounds may be measured. The whistle may be lengthened or shortened, by means of a sliding tube, to the hundredth part of an inch, so that it affords exceedingly minute variations in pitch, till the shrillest possible sound is reached. If a number of persons are placed at a distance of a few yards from the experimenter, their relative auditory capacity will be tested in a somewhat amusing manner.

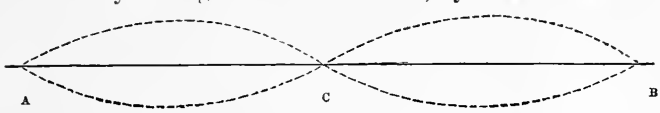


Fig. 4.—Showing Vibration of String Damped at the Middle.

There are certain phenomena associated with the vibration of strings that are as remarkable as they are important in a musical sense.

If we damp a string at its middle point —that is to say, bring down upon it any light substance such as a feather—and draw a bow across one of its halves, the untouched half will also be thrown into vibration. Let A B (Fig. 4) represent the string of the sonometer, and C the point damped, then on agitation we shall observe two segments known as loops, or ventral segments, which will continue vibrating even when the damper or feather is removed. Now damp the string at a distance of one-third of its length, and set in motion the shorter division. The longer portion will at once divide itself into two segments, so that the whole wire will be divided into three equal portions, as in Fig. 5. Between each segment is a point of apparent quiescence, called a *node*. The difference in the vibratory condition of these points and the segments themselves may be effectively demonstrated by the use of little paper riders. Place one on the node C, and another on the centre of each segment. The latter will be thrown off, while that on the node will maintain its seat. However small the agitation of the string at the nodes may be, it is obvious that they cannot be points of absolute rest, for, otherwise, the vibration of the entire wire could not be maintained.

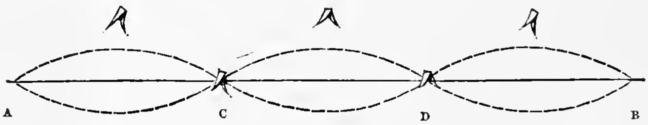


Fig. 5.—Showing Vibration of String damped at one-third of its Length.

Again damp the string, at a distance of one-fourth of its length, and pluck the shorter division. The longer or untouched portion immediately divides itself into three equal segments, separated by two nodes (Fig. 6). Place paper riders on each node and on the centre of each segment. These will be thrown off, while those on the nodes will remain stationary. Proceeding in this way, we can divide a vibrating wire into any number of ventral segments we please, the nodes between them being produced by the meeting and coalescence of direct and reflected waves.

We have seen that the *pitch* of a note depends upon the number of vibrations per second; the *intensity* of a note depends on the amplitude of the wave producing it. The greater the force applied to set a string in vibration, the greater will be its width of swing, and, consequently, the more powerful will be the impression of the wave upon the sound-board.

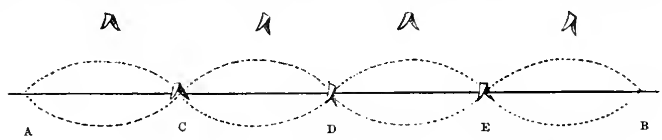


Fig. 6.—Showing Vibration of String damped at one-fourth of its Length.

The more force we apply to the key of a pianoforte, or the bow of a violin, the more intense will be the sound produced, but we do not thereby alter the pitch of the note, although, for reasons which will presently be apparent, we affect its quality.

Having determined the conditions upon which pitch and intensity depend, we turn to the consideration of musical *quality*. We commonly, but erroneously, employ the word *tone* when referring to the quality of a musical sound. The term is properly applicable to express a certain musical interval; but if we are to restrict ourselves to our own tongue, there is no alternative but to use the vague and unsatisfactory term *quality*. The French word *timbre* is much less vague, and is now pretty generally employed by musicians. Professor Tyndall uses the still more expressive term *clang-tint*, derived from the *klangfarbe* of Helmholtz. He justifies this on the ground of the complete analogy between light and sound. The perception of both is due to aërial vibrations affecting differently the organs upon which they impinge; and conveying, consequently, different impressions to the brain, the real seat of all our sensations.

As a tint in colour is the visual effect of rays having a special and constant rate of vibration, and a mixed tint is the result of the super-position of rays having different rates, so we may have a simple sound and a compound sound, which are produced by precisely similar wave-actions; so that we may speak of the tint or colour of a sound with scientific propriety, however much opposed the phrase may be to colloquial usage. A pure, simple sound is as rare as an absolutely pure colour; all natural tints are more or less blended; and every musical sound, from whatever source, is more or less compounded. To many musical people it will appear strange to be told that the "pure" tones of their favourite piano, or violin, are not simple, but mixed, and that the full and agreeable quality, or *timbre*, of such notes is entirely due to the fact that they are chords comprising numerous intervals between the fundamental and the fourth octave above it. This will become evident from the consideration of what has been stated respecting the sub-division of a vibrating string into segments which multiply as the point agitated approaches one end.

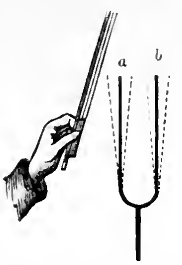
When a wire vibrates as a whole, there are always partial vibrations super-posed upon the primary one, and these secondary vibrations give rise to tones which, although masked by the fundamental, are nevertheless present, sometimes in considerable number. These notes are known as *Harmonics*, and are called by Tyndall *overtones*. They have also received the name of "upper partial tones," but the first of these terms seems to be the most technical, as it is also the one most generally employed. The existence of these harmonics may be readily demonstrated. If we strike sharply one of the keys of the pianoforte, or, better still, of the harmonium, and listen attentively as the sound of the fundamental dies away, we shall distinctly hear three or more of the harmonics. Those which are most prominent, and cannot fail to be heard by every disciplined ear are the octave, the twelfth and the double octave. Other overtones are present, as the third, fifth, seventh, and tenth, but they are not so easily distinguishable. The experiment had better be tried with some note below the middle C of the instrument, because the higher the fundamental, the more acute will be the harmonics, and consequently the more difficult will it be to detect them. A good plan to follow is to strike first the octave and then the twelfth of any note whose harmonics we wish to hear, and, when the sound has died away, to strike the fundamental. Our ears having thus become prepared, we shall the more readily discover the corresponding overtones. Proceeding in this way, we shall find the sixteenth plainly audible, but in all cases, the more quickly the finger is removed from the key, the more successful the experiment will be. The effectiveness of what is called "touch" in pianoforte playing, depends mainly upon the development of the harmonics. Much light has been thrown on this subject by the researches of Helmholtz. To this profound physicist the world owes the discovery that the distinction between one musical instrument and another in respect to *timbre* is due to the presence or absence of certain harmonics. If we could eliminate from the pianoforte, harp, and violin their characteristic overtones, and leave them their primary sounds only, these instruments would be undistinguishable from each other. The music of our finest orchestras would be shorn of that brilliancy and variety which result from an artistic combination of stringed and wind instruments, while the reeds of the bassoon, oboe, and flageolet would lose their peculiar character and become reduced to the same level of flatness and monotony.

Musicians long ago found out how much the "tone" of their stringed instruments depended upon the point struck, although they were unable to give any satisfactory theory upon which the determination of that point might be based.

If we strike the wire of our sonometer in the

centre, the sound it yields is dull and flat; but as we move the point agitated farther from the centre, the sound increases in brilliancy, although its pitch—which, as we have already seen, depends upon the length of the wire—remains the same. But if our wire is plucked too near its end, the number of ventral segments formed becomes so large that some of the harmonics are dissonant, and give a perceptibly disagreeable clang to the sound. Pianoforte makers place the hammers of their instruments at a distance from the ends of the wires of about one-seventh of their length, and thereby avoid overtones which would be a source of dissonance.

Helmholtz has devised an ingenious method by which a compound note may be analysed into its constituents. Before describing his plan, it will be necessary to explain what is meant by *resonance*, or *sympathetic vibration*. If a tuning-fork is sounded in proximity to another of the same size, and yielding, therefore, a note of the same pitch, it will set it in vibration; in other words, it will respond to the first, or resound sympathetically. In the same way, an organ-pipe of the proper length will respond to the tuning-fork, and a cylindrical glass jar having its column of air adjusted to the proper length, by pouring in water, will resound in a similar manner. If one of the forks is thrown out of tune to the smallest possible degree by loading one of its prongs with a pellet of wax, it will not resound to the other, because the equality between the rates of vibration is thereby disturbed; and if the organ-pipe is lengthened or shortened by the fraction of an inch, or a little more water poured into the glass vessel, resonance in like manner will be annihilated. The term "sympathetic" sometimes applied to these resonant vibrations is more popular than scientific. It is simply a case of synchronism, the vibrations of the resonant column being timed in exact accordance with those of the tuning-fork



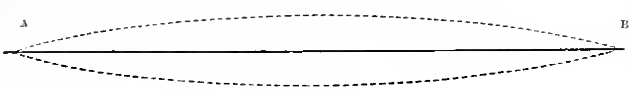


Fig. 7. — Sound-Wave from Tuning-fork.

or other sounding body. The length of a resonant column is always one quarter of the length of the wave which sets it in motion. Suppose, for example, that the length of the sound-wave produced by the fork is forty-eight inches, then the length of the glass jar must be twelve inches. When the fork vibrates from *a* to *b* (Fig. 7), it generates what is called a wave of condensation, proceeding in this case to the distance of twenty-four inches. This is regarded in this country as half a wave-length, because it is followed by a wave of rarefaction returning from B to A; but in France it is usual to consider it as a whole vibration.

If the resonant vessel, then, be twelve inches long, the wave will just reach the bottom and back again by the time that the rarefied wave commences its journey. This perfect synchronism produces reinforcement of the sound. Upon this principle are constructed the "resonators" used by Helmholtz in his analysis of compound sounds. They are oblong boxes of elastic wood with an opening, or embouchure, at one end for admitting the sonorous wave, and another on the top fitted with a flexible tube which may be applied to the ear (Fig. 8). The internal capacity of these resonators is so regulated that they will severally resound to notes of a given pitch, and to no others; that is to say, in a properly graduated series each will augment a note of its own pitch only.

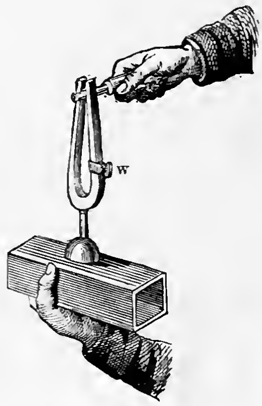


Fig. 8.—Tuning-fork mounted on Resonant Case; W, Clamp for lowering rate of Vibration.

Suppose, now, we have before us a series of twelve resonators adjusted to a given fundamental, its octave and ten more of its upper harmonics. On sounding, in front of the row of embouchures, an organ-pipe of the same pitch as No. 1 resonator, we should expect to find all the other resonators silent. Instead of this being the case, however, we shall notice, on applying the tubes to the ear, that resonance is established in several of the other members of the series. What does this prove? Evidently, that the note emitted by the pipe is not a simple but a compound one: that it is, in fact, a mixture of notes, all of them more or less feeble in comparison with the fundamental. By this method of analysis twelve or thirteen harmonics may be discovered as the constituents of many apparently simple notes,

especially those of the violin, their succession being as follows :—

Harmonics from the great C, the lowest note of Violoncello.

In some sounds, as those yielded by a tuning-fork and stopped organ-pipe, the overtones are so few and feeble that, for all practical purposes, such notes may be regarded as simple. Instances of sympathetic vibration are more common than is generally supposed. It has often been noticed that tremors have been set up in a glass shade when a particular note has been struck on a pianoforte in the same room, while it has remained perfectly unaffected by every other note. The mass of air in the shade has been of such dimensions that its vibrations have synchronised with those of the wire, and these shades, and even particular panes of glass, have been known to be broken by sounds of sufficient intensity and properly regulated pitch.

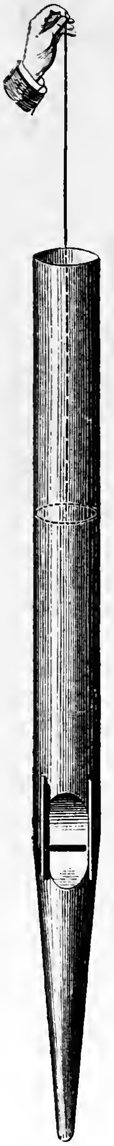


Fig. 9.—Vibrating Membrane in Organ-Pipe.

Let us now examine the aërial vibrations of wind instruments. The king of these instruments is, of course, the organ, whether we regard its magnitude, power, variety of orchestral effects, or the complicated acoustic and mechanical machinery by which these effects are produced. The pipes of the instrument, which sometimes number as many as five thousand, are both of metal and wood, the former being circular and the latter square. They are inserted into holes in the sound-board, or wind-chest, which is a reservoir of compressed air received from the bellows by means of leaden wind-trunks or conduits. Each pipe consists of a narrow conical *foot* and a long square or cylindrical *body*, and at the point of attachment is the mouth, or embouchure, which is an opening having a sharp, oblique edge *a* (Fig. 11). Against this edge the compressed air strikes as it issues in a thin current from a narrow slit at the summit of the foot *b*. The violence of the impact sets the air in the embouchure into rapid vibration, but if the action were confined to this point no musical sound would be produced. The vibrations are taken up and reinforced by the pipe, which acts as a resonator, so that the aërial column within is the real sounding body. Now, this aërial column vibrates longitudinally like a rod free at both ends, and divides itself into ventral segments separated by nodes just in the same way as the string of our sonometer. We should, therefore, expect the production of a fundamental note and its harmonics on the same principle as that enunciated in speaking of stringed instruments, but under modified conditions ; for here we have longitudinal, instead of transverse, vibration, and a column of air free at both ends instead of a string fixed at both ends. When an open organ pipe sounds its fundamental note, there is always a node in the centre of the pipe and a loop or segment on each side of it, because a wave is reflected from each end of the pipe, and both meet in the middle, producing condensation, which is followed by the usual rarefaction on their separation. This condition of the air within the pipe may be well demonstrated by the following experiment devised by Edward Hopkins, whose work on the organ is so deservedly popular. A thin membrane is stretched across a cardboard ring (Fig. 9), and suspended by a string so that it can be let down into a sounding-pipe, or drawn up at pleasure. When a musical note is being produced, the membrane will vibrate as it descends, but when it has reached a node the vibration will cease, because the air at that point is at rest. If fine sand is strewn on the membrane, it will dance up and down in its passage through a segment, but will cease to be agitated on reaching the node. On allowing the membrane to descend still farther and to pass the node, its vibration will recommence, and the grains of sand will again resume their dance. If we increase the force of the blast, the note will be raised an octave, which constitutes the first overtone of the pipe. On testing the condition of the vibrating air with the membrane we shall discover that the node has vanished from the middle of the pipe, and its place is supplied by a segment. In fact, we have now two nodes equi-distant from the centre of the pipe, and *four* segments instead of two. When the second harmonic is sounded, the column will be divided into six equal parts, and thus we find the ratio of vibration to be expressed by the numbers 1, 2, 3, 4, &c. We cannot make the same pipe produce any intermediate note between the primary and its

octave, because, when the aërial column divides itself into two equal parts, the rate of vibration is doubled, as in the case of the stretched string. Some organ pipes are stopped or closed by a plug.

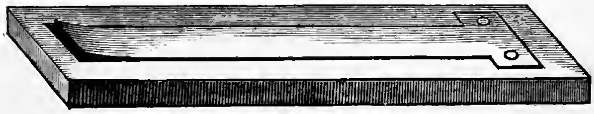


Fig. 10.—A Musical Reed.

A stopped pipe is one-half the length of an open pipe yielding the same note, for, as the sound-wave is arrested by the plug, that point becomes a node, and the rest of the pipe is occupied by a loop or segment. Such a pipe cannot be made to sound its octave, because the air, when set in vibration, divides itself into three segments instead of two, and consequently yields the twelfth as its first harmonic. By increasing the blast, we divide it into five equal loops, so that the ratio in this case is expressed by the numbers 1, 3, 5, 7, &c. The harmonics of a stopped pipe are very feeble, and the sound it emits, though mellow, is destitute of brilliancy and character. The most brilliant sounds of the organ are produced by reed pipes (Figs. 10, 12, 13). These are pipes in which the vibration is influenced by a reed, or tongue of metal, similar to those employed in the harmonium and concertina (Fig. 10). A simple form of the reed is seen in the toy called a Jew's harp, while a similar vibrating strip of metal is employed in every child's trumpet. The reed used in organ pipes is known as the "free reed." It is a narrow plate of copper fixed at one end over a rectangular aperture, so that when it moves up and down it just grazes the sides of the opening without altogether closing it. The pitch of the pipe is determined by the length of the reed, and a bent wire (*a*, Fig. 13), being placed in contact with it, can be moved up and down, and thereby practically lengthens or shortens the reed. In this way, reed pipes, which are constantly getting out of order from changes of temperature, can be tuned. They are usually surmounted by a conical tube, or horn, to increase the intensity of the sound.

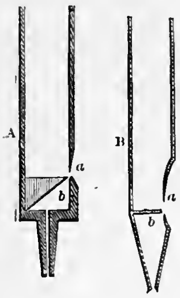


Fig. 11.—Mouthpiece of Pipes.
A, Wooden or Flue Pipe; B, Metal Pipe.

There are other reeds, called *beating* reeds, which, being longer than the aperture over which they are placed, entirely close it. Such reeds are employed in the clarionet, oboe, and bassoon, and the best organs are furnished with stops in imitation of these instruments. The distinction between the clarionet and the flute is, that the former is a stopped reed pipe and the latter an open one without a reed. The bassoon and oboe are supplied with a double reed, and the air is blown through a slit between them.

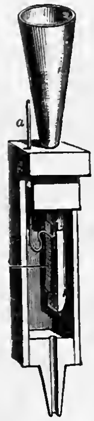


Fig. 12.—Reed-pipe.
a Wire for Tuning.

In tuning instruments, a narrow steel bar bent in the form of a U, and called a tuning-fork, is employed. The number of its vibrations per second is constant, and therefore its pitch is invariable.

Thus the fork yielding the middle A of the pianoforte makes 440 vibrations per second, and the C above it 512 vibrations per second. The reader may probably wish to know how these calculations are made. M. Savart's method is founded on the principle that a musical sound is produced by *taps* following one another with sufficient rapidity and in perfect periodicity. His apparatus (Fig. 14) consists of a toothed wheel which is made to revolve rapidly by means of a larger wheel. The teeth act against a card, and produce a musical sound. If we wish to ascertain the number of vibrations executed by any given note, we bring the sound of the apparatus into unison with it. The number of revolutions per second made by the wheel, multiplied by the number of teeth, will give us the number of vibrations of the card per second. The most perfect instrument of this kind, however, is the *Siren*, invented by M. Cagniard de la Tour, and improved by Helmholtz.

Fig. 13.—Reed detached.
a, Wire for Tuning.

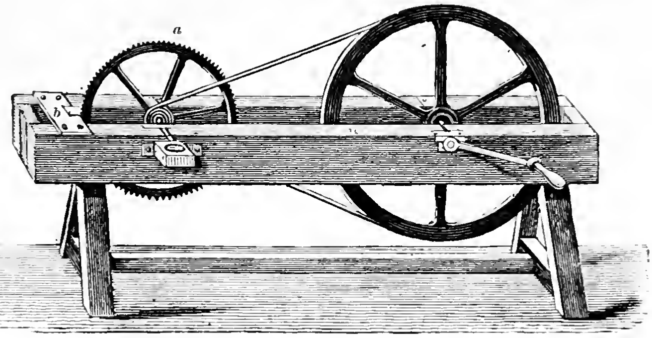


Fig. 14.—Savart's Apparatus for determining Rate of Vibration.
a, Toothed Wheel, acting on Card, *b*.

In this ingenious apparatus, a musical sound is produced by a rapid succession of puffs of air. A brass cylinder, B, is fitted with a plate pierced by a series of holes arranged in four concentric circles. These holes are pierced obliquely, and above them is a revolving disc similarly perforated, the obliquity of the holes being in the opposite direction, D. When air is urged into the cylinder and through the perforated plate, it is evident that the upper disc will be driven round by the impact of the currents against the sides of the holes. An axis (*b*, Fig. 15) is fitted into the disc and revolves with it. The upper end of the axis is cut into the form of a screw, and its revolution sets in action two dials C, by which the number of revolutions is recorded. By properly regulating the blast of air from the acoustic bellows, we can cause the siren to yield any required note. The number indicated by the dials, multiplied by the number of holes, gives the number of vibrations, or puffs of air, in the given time. The four series of holes number respectively 8, 10, 12, and 16, and these can be combined in any way by the pegs *c*, *c*. If we open, for example, the series 8 and 16, we shall get a note and its octave, whether the pitch be high or low; or, if we open the series 8 and 12, we shall have the interval of a note and its fifth. By means of the double Siren, which has an additional cylinder and disc turned upside down and revolving on the same axis, other intervals can be sounded, and the *beats*, which always occur when notes nearly in unison sound together, can be studied. These beats may be readily produced by forcibly striking on the piano two notes separated by a semitone, as C and C sharp. The lower the notes selected for the experiment the more violent will be the beats. This is a phenomenon of wave interference, the swelling and falling in the sound being caused by the two sonorous waves alternately reinforcing and weakening one another.

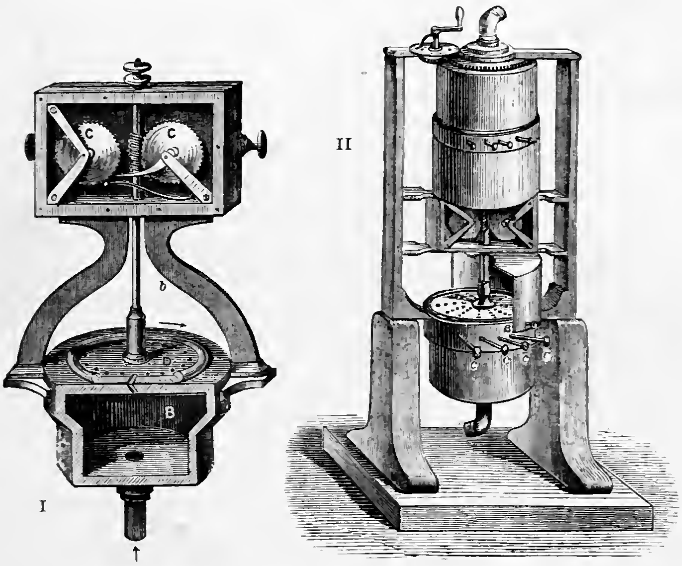


Fig. 15.—I., Cagniard's Siren; II., the Double Siren of Helmholtz.

TOUCH.

By F. Jeffrey Bell, B.A., F.Z.S.

On a previous occasion* we have spoken of the Hand, and we then dealt especially with its structural characters; the sense with which we shall now deal finds, in man at any rate, its highest development and its greatest perfection in the self-same organ. It is to the combined effects of its nerves of sensibility, and of the muscles that move its parts that the musical performer owes his "delicate touch," and the artist his "lightness of hand"; and, again, as it is the organ by which we test, by which we weigh, by which we grasp, it affords an admirable example of those sensations of pressure and of temperature which, when associated with what has been well called the "muscular sense," go to make up in all its completeness the sense of touch. With these divisions of our subject we shall shortly deal in some detail, but for the moment we will take the skin-covered hand as a text for some remarks on the general apparatus of the sensory portion of the nervous system.

If we press the closed eye-lid on the eye-ball, we see a gleam of light: if a disordered system produces congestion in some of the blood-vessels of the head, we hear a "singing in the ears:" but

* "Science for All," Vol. II., p. 261.

if we press our finger on a marble, we neither see it nor hear it—we *feel* it. To translate this sentence into another style, there are in various parts of the body special "end-organs" for special senses—for sight, and for hearing, as well as for smell and for touch; and these end-organs, howsoever affected, never respond to the stimulus in any but one way; they may produce a sensation of sight, or of hearing, or of touch, but never of more than one, and that one is always the same. No better example of this law can be found than that presented by those cases in which accident or disease has affected the nerve (and it is by these that all the end-organs communicate with the brain) which supplies the tactile portions of the eye-ball; in less distressing circumstances, a finger placed on the eye-ball is, especially if the pressure be light, immediately felt; but, when the nerve in question is affected, the whole of the eye may be passed over by the finger, and all that the patient will be able to tell of, will be what he learnt by the shadow of the finger passing over the field of vision.

We come next to the question, where are situated the end-organs of the sense of touch? And to this, one answer alone will ever be given by those who have undergone any operation in which the skin has been cut,—the answer is, that the end-organs in question are situated in the skin. But this is only to a large extent true, and not altogether so, as anatomy itself would tell us, and as our, in many cases, daily experience quite sufficiently impresses on us. It has, in fact, been observed that some of the most remarkable of the special sense-organs found in the skin are found also in the delicate membrane by which the folds of the intestines are held together. That some organs—the heart and the lungs, for example—are insensible to sensations of touch, has been known, at any rate from the time of Harvey, whose account of the experiment differs in nowise from his others, in being well worthy of quotation. A young nobleman, suffering from an abscess on the side of the chest, had the just-mentioned organs a good deal exposed. "I saw a cavity into which I could introduce my fingers and thumb. Astonished with the novelty, again and again I explored the wound. . . . Taking the heart in one hand, and placing the finger of the other on the pulse of the wrist, I satisfied myself that it was indeed the heart which I grasped. I then brought him to the King (Charles I.), that he might behold and touch so extraordinary a thing, and that he might perceive, as I did, that unless we touched the outer skin, or when he saw our fingers in the cavity, this young nobleman knew not that we touched his heart." Noting here that all that is stated is to the effect that there was *no sensation of touch*, we may point out that the brain and the spinal cord have been conclusively shown to be insensible to this sensation; and, in fine, the sense of touch does not exist in any parts where the proper organs for that sense are absent.

Before going any farther into our more proper physiological researches, we shall do well to imitate all good physiologists, by attempting to get a clear idea of the structure of these sense-organs. They are broadly divisible into three groups, all of which present the following essential characters:—One or more nerve-fibres, an outer covering capsule, and an internal core of soft, granular matter; the *end-bulbs* are more or less spheroidal in shape, and are ordinarily set, as in the subjoined figure (Fig. 1), in

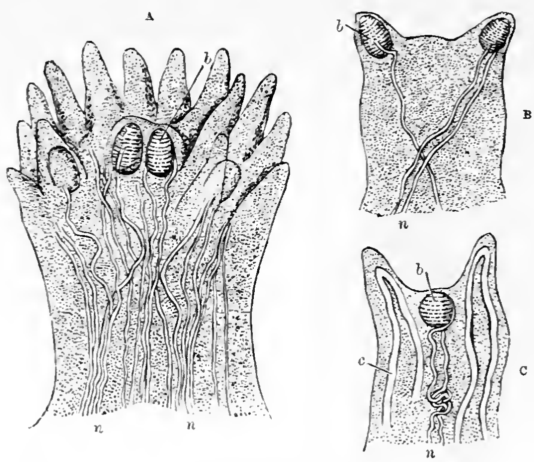


Fig. 1.—End-Bulbs in Papillæ. A, from Tongue; B C, from Lips. (b) End-Bulbs; (n) Nerves; (c) Capillaries.

those elevations of the surface of the skin which are known as *papillæ*. The *touch-bodies* (*corpuscula tactûs*) are nearly twice as large as the end-bulbs, and are generally of an oval form (Fig. 2). They are best seen in the skin of the terminal joints (*phalanges*) of the fingers, where they are very numerous—so many, indeed, as one hundred having been observed by a German physiologist—but, of course, they are not absent from other parts. The third set of sensory organs are known as the Pacinian bodies (or bodies of Vater, who gave an account of them in the year 1741). These are very much larger organs, being, in some cases $\frac{1}{10}$th of an inch long. They are attached by a narrow stalk to the nerve-branch by which they are supplied; and,

as will be seen in Fig. 3, their outer covering consists of a number of concentric coats, of which, in some cases, as many as sixty have been made out by the patience of microscopists, and which

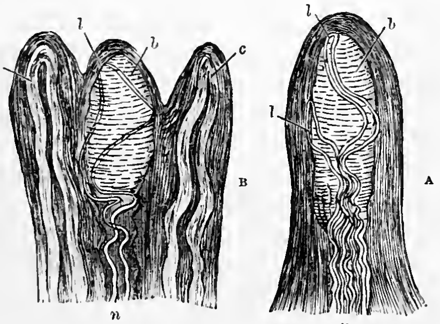


Fig. 2.—Touch-bodies.
(A) Simple Papilla; (B) Compound Papilla; (b) Touch-body; (c) Capillaries; (n) Nerves; (l) Nerve-loop.

are separated from one another by small cavities containing fluid. Through these coats the nerve passes on its way to the central cavity, in which it ends by a swollen knob-like enlargement. As many as six hundred of these curious bodies have been found in the skin of the human hand, but the most remarkable place in which they have been found is the mesentery (or membrane connecting the coils of the intestines) of the cat. For a time, it was thought that this distribution indicated that the corpuscles in question were not tactile organs, but it is now known that the parts which they supply are remarkably sensitive; and it has been jocosely suggested that it is this sensibility which in dyspeptic cats is the cause of that nocturnal music by which the sleepless are continually delighted; but whether this is their real function, or whether they are in some way associated with the springing action of this group of animals, is a question on which discussion would perhaps easily provoke that sleep for which we have before now longed.

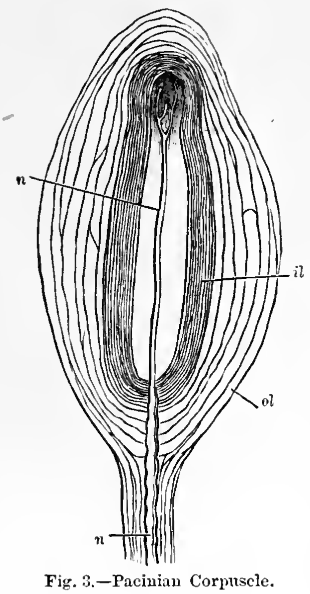


Fig. 3.—Pacinian Corpuscle.
(n) Nerve; (il) Inner Coats; (ol) Outer Coats of Envelope.

As may be easily imagined, the parts of the skin are supplied in various degrees by these end-organs, and the extent of this difference is perhaps best shown by the following table, compiled by the illustrious German physiologist, Weber, who obtained his results by the following method:—The legs of a pair of compasses, to the ends of which small pieces of cork were attached, were brought to bear on various parts of the body of a blind-folded person, and these were brought as near to one another as they could be brought while producing distinct sensations. The distances thus obtained were:—

Point of tongue	half of a line.*
Palmar surface of third phalanx	1 line.
Red surface of lips	2 lines.
Palmar surface of second phalanx	2 ,,
Palmar surface of metacarpus	3 ,,
Tip of the nose	3 ,,
Edge of tongue	4 ,,
Skin of cheek	5 ,,
Tip of great toe	5 ,,
Hard palate	6 ,,
Back of hand	8 ,,
Mucous membrane of gums	9 ,,
Lower part of forehead	10 ,,
Lower part of the back of the head	12 ,,
Skin over knee pan	16 ,,
Skin over sacrum†	18 ,,
Back of foot	18 ,,
Skin over breast bone	20 ,,
Skin beneath occiput	24 ,,
Skin over spine, in back	30 ,,
Middle of the thigh	30 ,,

To put the results in a more general way, we may say that the sensitiveness of the skin is greatest at the points most distant from the trunk—that is, in the toes and fingers, and that, as we approach the more central region, we find this sensitiveness diminish. This rule may be carried still farther, and we may say that with greater rapidity of movement there is greater sensibility, inasmuch as it has been observed that the tips of the fingers, as compared in sensibility with the shoulder, are three times more sensitive than the toes, as compared with the thigh.

To what is all this sensibility due? How is it that we have any knowledge at all of the bodies that we touch or that we feel? These are questions which we shall have to answer, but before we do so let us observe one curious point. The more or less complicated end-organs, the structure of which we have been examining, have for their function to inform us as to the characters of the body touched, and under ordinary circumstances they fulfil their

* A Paris "line" is one-eleventh of an English inch.

† Lowest part of backbone.

purpose well enough; but if we subject these sense-organs to ever so simple deceptions, they will easily mislead us. For example, let us place a marble between the middle and ring fingers, we feel one marble; but let us cross the fingers so that the inner face of the middle finger comes to be opposite the outer face of the ring finger, and let us place a marble between the two tips thus arranged; with closed eyes we shall then have the sensation of touching two marbles. And why? Because, under ordinary circumstances these two surfaces, the outer one of the ring finger, and the inner one of the middle finger, do not touch the same object, and experience has taught us that when these two surfaces are touched, there are two distinct objects brought to bear upon us. To complete therefore our Sense of Touch we have need to exercise our judgment, and to draw on our experience; and for this purpose there is connected with these end-organs a nerve which passes to the brain and delivers there the message from the outer world; and just as with imperfect end-organs in the eye the colour-blind (p. 316) assert against all the world that the cherry is green, so with disordered tactile sensations we judge that to happen which the sense of sight, when perfect, would warn us against concluding, and which under other circumstances would be regarded as ludicrous or impossible. It is therefore in the brain that we form the ideas of the bodies that we touch, and what we call our knowledge of the external world depends on the healthy and regular play and interaction of the end-organs of the nerve and the reasoning organ of the brain.

Let us develop this a little further. Two points of a compass at a certain distance are distinguished as two when pressing lightly; when pressing more heavily, as one. A body somewhat larger than the distance between the two points gives rise to a sensation of a single object. Now, it is clear that in all these cases a number of different end-organs are touched, and we have to see, if we can, how it is that the results are so different; the matter has been so fully worked out in the eye, that we shall most easily get to a definite result by briefly stating the chief known facts in the case of this organ. In it the nervous termination—the *retina*—is provided with a number of cones, of which the much lamented Max Schultze, of Bonn, made out fifty in the small space of one-fifth of a millimetre (ten millimetres are not as much as two-fifths of an inch); using the ordinary sign for one-thousandth part of a millimetre, the Greek μ, and knowing that one-fifth of a millimetre is equal to 200 μ, we see that the centre of each one of the cones was distant four μ from that of its neighbours. Now, when we examine objects placed close to one another, or at so great a distance from us as to seem close, we observe that when they are, or strike us as being within this distance of four μ, they appear to be one; and speaking, therefore, broadly, although arriving quite fairly at the truth on which we are now desirous of insisting, we may suppose that there exist in the brain *areas of sensation* which, within limits, correspond to those in the retina. But against this correspondence we have to put the fact that when two neighbouring cones are stimulated they may give rise to one sensation; and this, as it seems, is due to the fact that the brain, under certain circumstances, *fuses* sensations; the varying results obtained with the compasses and with the single body are now explained, and we have some light thrown on the difficulty to which we have referred. Even here, however, the matter does not end; in this as in other affairs, the brain is capable of education, and the skilful touch of the blind and the sharp eye of the astronomer gain, as we now know, complimentary epithets which should be rather applied to the sensation-areas in the brain, which are the parts that pass judgment on the objects that stimulate these eyes and fingers; but it is needless to insist on the power of tactile discrimination which can be gained by practice, for we all know the value of this sense to the blind.

The sense of touch seems to be very simply developed in the jelly-fish and its allies, inasmuch as in them there are organs which on pressure shoot out a thread (Fig. 4), by which they are enabled to attack the body pressing on them; and many of these animals are also provided with tentacles, which must have a similar function; many worms are provided with stiff processes, and some of these are, in a large number of cases, set on long tentacles; in the lobsters and crabs, where the general surface of the body is very hard, and in the allied insects (flies) various parts, especially the antennæ (feelers), are provided with out-standing rods which are connected with nervous swellings. In the vertebrata there is a similar set of organs, and we well know how, in ourselves, the tickling of the end of a hair appears to increase the tactile sensation; while the whiskers of the cat, and the "beards" of fishes, are organs of just the same type. In the scaled fishes there are other curious arrangements, but as they all depend essentially on the presence of end-organs, it will be unnecessary for us to enter into them in any detail; could no better reason be given, we might remind

ourselves that we have still to speak of the sense of temperature, of the muscular sense, and of what is known as to the laws of the sensation of pressure.

To this last we will first address ourselves. Much of what we ever know about matter is due to the

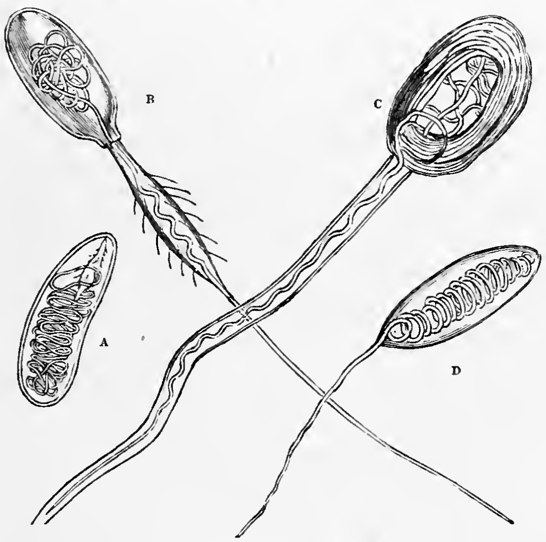


Fig. 4.—Thread-cells. (*After Moseley*)
(A) Quiescent; (B, C, D) Active.

effects produced on us by pressure, and it will be interesting to see how far this sense really helps us. Our estimation of pressure varies in accordance with a law which goes by the name of its chief expositor —Fechner; and as its most exact formula can only be given by the aid of the integral calculus, it will be better to take an example. Suppose that we are able to distinguish between ten grains and eleven grains, but that we cannot distinguish between ten and ten and a half grains: or between ten and a half and eleven grains; then we can distinguish between ten and eleven pounds, but not between ten and ten and a half pounds, or between ten and a half and eleven pounds. Again, we cannot distinguish between pressures when they succeed one another with more than a certain degree of rapidity; and yet again, when pressure is equally applied, as it is to a finger dipped in a quantity of mercury, there is sensation only at the point nearest to that at which the pressure ceases. Most of us, indeed, must know the truth of this, for when we have dipped a finger into a basin of mercury and moved it up and down, there has been felt a sensation of a ring as it were moving along the finger.

The sense of pressure is best brought to perfection, when the object of which we wish to know the weight is held in an unsupported hand, for we then bring to bear upon our judgment the sensations excited by the *muscular sense;* as has been well observed, "when we want to tell how heavy a body is, we are not in the habit of allowing it simply to press on the hand laid flat on a table; we hold it in our hand, and lift it up and down. We appeal to our muscular sense to inform us of the amount of exertion necessary to move it, and by help of that judge of its weight." But we also need the aid of this muscular sense in examining the form of a body; for as we move along it, the varying movements of our arm and hand help to inform us of its elevation and depressions, of its angles or its curves. Yet again, many of our experiences show us how closely the muscular sense is affected by and affects the more proper sense of touch; a heavy portmanteau held by an insufficiently small handle produces sensations of discomfort which react on the muscular sense, and we find the weight too heavy for us; a body pressing on our hand by its narrowest edge seems far heavier than when it presses by its broadest. We associate a light body with a small, and a heavy body with a large area of pressure, and we adapt our muscles and our energies to deal with them accordingly; and here, as elsewhere, what is new is disagreeable, and what is unexpected is painful.

The great French physiologist, Xavier Bichat, insisted on the value of the combined action of the two hands as an aid in tactile sensations; arguing with extreme force from a supposed case of a man born blind who had one hand endowed with the ordinary capabilities, and the other incapable of bending its fingers, and having a thumb which it could not oppose to the digits. Imagine such a one having to carry a sphere; by one hand he would be informed of its roundness, while the other, touching the body only here and there, would give quite a different report; rendered thus uncertain, "the blind one would carry it with difficulty; he would even have, perchance, two different ideas as to the form of the body. His ideas would be more precise if he condemned one of his hands to inaction, just as he who squints turns the feeble eye from the object that he views, so as to avoid confusion." Without pursuing any further the argumentations of this physiologist as to the "necessary harmony in the action of two symmetrical organs," we may point out that the deep-seated "bilateral symmetry" of all the higher animals seems, from its widespread occurrence, to be one of the most important of factors in successful existence.

The physiologist already mentioned—Edouard Weber—has also made some observations on the

power possessed by us of judging between different weights; the chief interest of which is that they throw some light on the processes going on in the brain; which organ is, as we have already pointed out, the final arbiter in all sensations. If a weight of four ounces be replaced after ninety seconds by one of five ounces, the difference between them could, it was found, be correctly judged; but if weights of fourteen and a half and fifteen ounces were taken, it was found necessary to apply the second weight after forty seconds. Bearing in mind the greater difficulty of discriminating between fourteen and a half and fifteen, as compared with four and five ounces, as is shown by Fechner's law, we see that the two cases are both of value, as indicating in the first place that the brain retains for a time an exact idea of the weight pressing on the hand, and that in the second place this impression gradually dies away; so that within the limits of the above law, the brain has been shown to have so far forgotten a certain sensation in forty seconds as to be unable to give a correct account of a weight not much greater than that which produced it, while one, within proportions twice as great, is remembered for about twice the same period.

Let us turn now to a rapid review of what is known as to the sense of temperature. It is very curious that the left hand is, in this particular, more sensitive than the right. Some importance has been attributed to the fact that to the whole hand water seems hotter than to a single finger; but if we bear in mind where it is that the "seems" comes in, it will be clear that a large number of heated points will produce a greater effect than a very much smaller number. The following, however, is a very curious fact, and our knowledge of it is due to that same German observer to whom we have had to refer so often; a cold body feels heavier than a hot one of the same weight. It is difficult to understand how this is, but the observation is of great importance as indicating that the sense of temperature is closely connected with that of pressure. Other series of observations have brought out the following points:—Great changes produce chill or feverishness by affecting the blood-supply of the skin; lesser changes are most accurately observed between 27° and 33° on the Centigrade thermometer; below this range, seven degrees are as easily recognised as six degrees above it; different parts of the body differ in sensibility, as we all show when we kneel in front of a fire, for then the highly sensitive lips and cheeks most rapidly produce the sensations we desire. So, again, the palms are more sensitive than the backs of the hands; and the chief charm of seeing a man standing with his back to the fire is perhaps to be found in the knowledge, gained by ourselves from experience, that he so stands because he is not so very cold to start with. The great difference between the sense of temperature and that of pressure lies in the fact that the former is relative to our own body temperature of a little over 98° Fahr.: it is by this that we judge whether what we touch is hot or cold, and it is this also which informs us of the changes that are taking place in ourselves. But it is long before we *feel* hot or cold that there comes into action that mechanism by which the skin is adapted to fresh, and almost dangerous, conditions. Exposed to the Turkish bath, the skin rapidly puts itself, by its nervous messengers, in communication with the blood-system, the vessels of which expand and so allow of that increased supply of watery vapour, the loss of which and the vaporisation of which are the agents by which the body is kept at its proper temperature; brought under the influence of cold, the skin again sends off a message, the vessels in it contract, and the general temperature remains constant.

While it has been difficult to keep what we would say within the prescribed limits, it is now difficult to sum up what has been said all too briefly; but we have learnt this—that the sense of touch is our most ordinary and useful means of communication with the outer world. Its most delicate organs are placed in parts which can most rapidly and easily inform us of what is going on outside ourselves; and they, while impressing their lessons on our brains, are also enabled in even the lowliest forms to respond with enormous rapidity to what seems to be danger, and to put the animal not only into a defensive but also into an offensive position. On another opportunity we may be able to develop in greater detail the striking aphorism that "Touch is the mother of all the senses."

ANIMAL COLONIES AND CO-OPERATION.

By Andrew Wilson, Ph.D., F.R.S.E.

Amongst the many unheeded, but interesting forms of animal life with which our ditches and ponds teem in the warm summer time, the little animals known as *Hydræ* stand out conspicuously in the eyes of the naturalist. The interest centering around the hydræ arises not from any characters likely to attract the ordinary observer. These animals have nothing to boast of in the way of size—their ordinary dimensions exhibiting a quarter of an inch as their extent in length, whilst a hydra half an inch long would be regarded as a giant of its race. Nor is the appearance of the hydra at all suggestive of its mythological namesake of the hundred heads which the redoubtable Hercules slew near the Lernæan lake. Imagine a little green tubular body, about a quarter of an inch in length, attached by one end to a bit of water-weed, and bearing a mouth-opening surrounded by feelers or tentacles

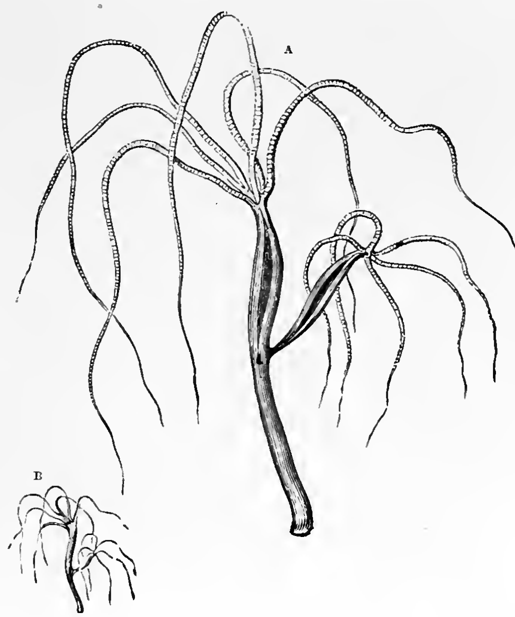


Fig. 1.—Hydra viridis—(A) Magnified, with Embryo ready to detach itself; (B) Natural Size.

at the other extremity, and you will have summarised shortly the main features of the hydra and its kind, as these features are observable by aid of a hand-lens (Fig. 1). Such is the little denizen of our pools which we propose to select as the subject of a short discourse on animal colonies and co-operation; and even if the result of our investigations be not over-important, we may nevertheless contrive to evolve some interesting facts in natural history from a study of

"The green mantle of the stagnant pool,"

and its inhabitants.

That the hydra is a sensitive being will be obvious to any one who touches its body or tentacles. Both portions of its frame will shrink and contract on the slightest touch. And the purpose of this sensitiveness is not hard to discover. For when an erratic water-flea, bustling through the waters and jostling its fellows like some self-important magnate in higher life, touches the outspread tentacles of the hydra, these little organs are folded round the struggling body, and a new relationship—that of relentless captor and struggling prey—is quickly formed. The water-flea will struggle violently at first, but will speedily be overcome and be drawn towards the mouth of the hydra, and thus engulfed. Very noteworthy, however, is the stillness which succeeds the first violent efforts of the prey to escape. So quickly does its demeanour change that we might well conceive its having been suddenly paralysed. And so, in truth, the captive has been rendered helpless. If we place a hydra under the microscope and gently press its soft body, we may see numerous little thread-like darts emitted from sundry "cells" which are embedded in the tissues of its frame. These cells are named "thread cells," from the form of their contained weapon; and from the manner in which they rupture and burst on being irritated there seems little reason to doubt that each thread-cell is a miniature poison apparatus, calculated to paralyse the prey. Cells of similar nature constitute the offensive weapons of certain near neighbours of the hydra, of which the jelly-fishes are the best-known examples; and more than one unwary sea-side visitor or tropical voyager has had good and sufficient cause to regret the liberality of Dame Nature in supplying these creatures with poison-darts of such virulence and power (Fig. 4, p. 308).

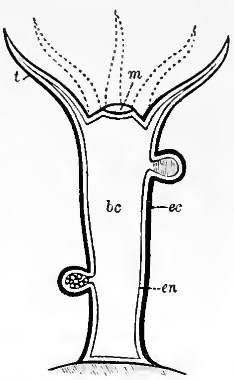


Fig. 2.—Section of Hydra. (*ec*) Ectoderm; (*en*) Endoderm; (*t*) Tentacles; (*m*) Mouth; (*bc*) Body-cavity.

The hydra's body exhibits anything but a complex structure. We have already compared it to a tube; and the comparison is perfectly just. The diagram (Fig. 2) will convey an adequate idea of the simplicity of the body in question. We see that it consists of two layers—an outer, *ectoderm*, and an inner, *endoderm*. These enclose a central cavity or space, the *body*-cavity, and of this space the tentacles or feelers are mere upward prolongations. Such is a fair statement of the anatomy of a hydra. When food is captured and swallowed by the hydra, we may thus discover that it passes, not, as in other animals of our acquaintance, into the stomach as the first portion of the digestive apparatus. In our hydra the prey simply enters the body-cavity, which serves the animal for a stomach, and in which the food is duly digested. Thus we find illustrated the liberally marvellous adaptation by living nature of simple means to complex ends; for in hydra we see a simple body-cavity, through the vital properties and powers of its walls, temporarily discharging all the important duties and functions of a stomach and digestive system.

The aim and end of digestion is, as every one must know, to provide a fluid—the blood—for the nourishment of every part of the frame. In higher animals this fluid is duly prepared in the digestive system, absorbed therefrom, and after further elaboration transferred to the blood-system, by which it is circulated through every part of the body. In hydra, a similar result is accomplished in an infinitely simpler fashion. The blood prepared by the digestion of the food simply circulates slowly through the body-cavity in which it was formed, being wafted, so to speak, by the little *cilia*, or lashes, which line that cavity. The nutrient fluid thus comes directly in contact with the cells and tissues of the hydra's body; by these cells and tissues it is duly absorbed; and the growth of the body is thus provided for in a manner as perfect as is represented in higher life. Thus much for the general life-history of the hydra; and to the details thus furnished may be added the intelligence that no traces of nerves are to be detected in this animal, its sensitiveness notwithstanding. Such a result is by no means surprising to the physiologist, who knows that many plants are acutely sensitive in the absence of nerves. But as these and allied matters have already been discussed* in these pages, we may turn to "pastures new," and to sundry features of interest connected with the production of new hydræ, and with the continuance of the hydra-race in time.

* "Nerves and No Nerves," "Science for All," Vol. I., p. 179.

Three methods of increase prevail in hydra-life, and we may commence our investigation of its history in this respect by noting the simplest of the three processes. It may be further noted that what we shall learn of the increase of hydra will materially assist us in understanding the subjects with which this paper professes specially to deal. The hydra may be said firstly to possess a power of reproduction by "division" of its body, a process otherwise known as that of *fission*. About the year 1744, an observant naturalist, named Trembley, published the results of his experiments on these very animals—the "fresh-water polypes," as they were and are still called in the language of popular zoology. These results were, to say the least, of a startling nature, and opened up a new field of speculation concerning the animal constitution and its proclivities. Shortly stated, Trembley's experiments showed that if a hydra be divided longwise a new animal will in time grow out of each half. If cut crosswise, the same result is noticed. If a hydra-body be "minced" into several small portions, each will in due time reproduce a perfect hydra. Even if, as Trembley proved, we turn a hydra inside out, like the finger of a glove, the animal will comport itself with a resignation which humanity is not over-prone to affect under injuries of infinitely less serious nature, and will eat and digest its food as if it had been left in its normal condition. We may explain this wonderful elasticity of constitution by appealing to the lowness of the animal's organisation. The hydra is not alone in its successful sufferance of injury. For the nearly-related sea-anemones suffer division meekly, and flourish each, as two bodies, through the destruction of one. Such animals sustain no great nervous shock in these operations. Each part or tissue is as vital as every other part, and is thus capable of perfectly reproducing lost parts. In the higher animal all parts are not of equal value in such work, and any serious loss of substance deals a blow to neighbouring parts and to the general vitality, effectually preventing the renewal of so much as a joint of the fingers or toes in higher existence—although, indeed, the newts and salamanders, amongst back-boned animals, reproduce toes and tails almost at will.

The hydra possesses in its *ova*, or eggs, a second and decidedly more usual and normal means than the preceding, for reproducing its kind. Each egg,

undergoing development, in due time becomes a perfect hydra. But the third and last process is that which must claim our attention at present, as serving to explain the colonial habits of animals, to be hereafter noted. This third process is that of *gemmation*, or "budding," a term sufficiently familiar as applied to plant existence, but which, as affecting the animal world, may possibly sound strangely enough in the ears of many readers. Nevertheless, animals may and do "bud," and the hydra presents us with this seeming exception to the laws of animal growth in its most typical phase. During the summer months, the hydra may be seen to exhibit little projections on the sides of its body, and usually towards the rooted or attached extremity. To the ordinary observer, these outgrowths might at first appear as some abnormal or diseased products; but as time passes their true character becomes apparent. Little projections begin to appear at the free end of the outgrowth, and assume the form of miniature feelers; whilst a further growth of the little body in question transforms it into a young hydra (Fig. 1), resembling its progenitor, or parent stem, in every detail save that of size. The hydra has, in fact, converted itself by this process of budding from a simple into a double or compound animal. For the young hydra is a connected process of the parent, the simple body-cavity of the latter being continued into the equally simple interior of the young; and a miniature colony is thus formed, fed by two mouths, and enjoying the fruits of co-operative labour in the work of digestion and nutrition at large. It may happen also that the young hydra bud, whilst attached to its parent stem, may in its turn, and in its own history, imitate the process to which it owed its own birth. The young hydra may be seen to "bud" in its turn, and to produce a miniature of itself: three generations of hydræ thus adhering together to form a connected and compound organism. But this state of affairs is not a permanent phase of hydra history. Sooner or later the young hydræ, like precocious offspring anxious to assert their independence, will sever their connection with the parent-body, and float away through the water to seek a new resting-place, and begin life on their own account.

Leaving this stagnant pool, with its quota of curiosities in the way of zoology, let us seek a different sphere of observation. Now we are strolling along a sea-beach, and peering amongst the "jetsam and flotsam" which the waves have tossed upon the shore. The sea-wrack is crowded with the treasures which constitute the delight of an inquiring mind and "the harvest of a quiet eye." Here, however, we light upon some objects more curious than the rest of those which form the sea-spoil around us. An oyster-shell has been torn from its bed, and has been swept landwards by the force of the waves. Growing upon it we perceive certain plant-like forms of symmetrical form and of graceful outline (Fig. 3). Regarded casually, they might be thought some marine plants of curious kind, which mimic in striking detail the forms of the fir trees in the

Fig. 3.—Sertularia, or Sea-Fir.

woods beyond the beach. Here, again, on another shell, are certain other plant-like organisms. A mere glance seems to afford a sufficient guarantee of their plant-like nature; and unscientific but enthusiastic lovers of nature will glean these treasures of the sea-wrack, and duly honour them, as strange

"sea-weeds," with a prominent place in the herbaria which form pleasing mementoes of a well-spent holiday by the sea. The fir-trees in miniature which spring from the oyster-shell have been named *Sertularia*, or "Sea-Fir;" and the sea-weed organisms may be termed "Sea-Mats," or, in scientific language, *Flustræ* (Fig. 6).

What is the nature of these plant-like forms, and what is their rank in the scale of creation? To answer these queries, let us procure living specimens of both by aid of the dredge. From a moderate depth in the sea, we procure specimens of the plant-like forms of the oyster-shell by the dozen, and we hie homewards with our treasures, duly preserved in their native water, for microscopic examination. We examine our "sea-firs" first, and a wondrous spectacle meets our view. We are now looking simply at a small portion of a branch, but the branch is typical of the whole "sea-fir." Our first glance shows us that, so far from inspecting a *plant*, we are observing a very typical *animal*. Instead of leaves or flowers, the branches of our plant-like "sea-fir" bear hundreds of little cups, in each of which a little animal form is contained. As they lie under the microscope we may learn much regarding their personal history. There is one which, as we look, is pushing itself forwards and prominently into notice. As it seems to expand before our eyes, we see that its little head is crowned with tentacles or feelers, in the centre of which a mouth exists. The margins of the branch are covered with horny cells or houses, each containing its little "tenant at will;" and as each tenant expands its tentacles, or hurriedly contracts them and itself as well on the slightest alarm, the spectacle which meets our view is both wonderful and interesting beyond description. Waving backwards and forwards in the surrounding water, the feelers evidently serve as the active parts of the animal *commissariat*, and sweep food-particles into the mouths they encircle. We have seen animals like these before. The tentacles, and the central mouth, and the little body—or, at least, as much of it as we can see—all suggest the hydra of the fresh-water pool, and no less does the mode of life of our "sea-firs" recall that polype's general history. Is the resemblance anything more than superficial? or is the likeness a real and veritable one, founded upon a true correspondence in nature? Let our further investigation of the sea-fir supply the answer.

Our "sea-fir" consists, as we may readily observe, of a main stem and branches, upon which are borne the little cups containing the animals which we have just noted to present a striking likeness each to a hydra. A further investigation of the stem and branches shows both to be hollow, and an equally notable fact is that of the branches being in free and full communication with the cups. A sectional diagram of a sea-fir (Fig. 4) would, therefore, appear thus:—

Outside we should find a horny covering (*c c*), which supports and gives strength to the entire organism, and which also expands to form the horny cups (*d d*) in which the little animals reside. It is this horny layer which remains when the living and softer parts have disappeared, and to the presence of the horny skin is due the preservation of the "sea-firs" in their dried state, as we find them tossed upon the sea-beach. Each little animal of the "sea-fir" colony possesses, as we have seen, a mouth (*m*), surrounded by tentacles (*t t*), the mouth leading into a simple body-cavity (*b c*), exactly as in hydra. No less notable is the fact that the layers of which the bodies of the sea-fir animals are composed resemble those of hydra, and consist of an *ectoderm* (*ec*) and *endoderm* (*en*), as in the latter polype. Next we discover, from our section, that the body-cavity of each little being leads directly into the hollow (*a a*) of the branch on which it is borne; and thus a free and perfect communication exists between any one animal of the sea-fir and every other denizen or neighbour-animal.

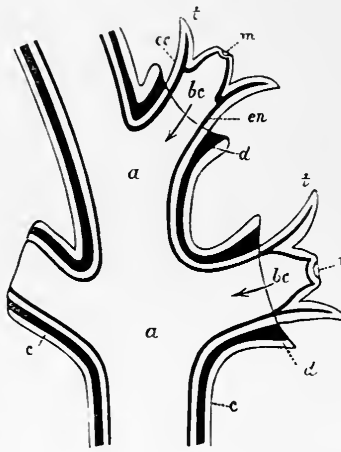


Fig. 4.—Sectional Diagram of Sea-Fir.

Let us consider now the life-history of such an animal as we have discovered this sea-fir to be, with the view of noting its essential and special characteristics. It is thus, firstly, a *compound* animal, and may justly be termed an *animal colony*. It consists of hundreds of similar beings, bound together in the closest fashion, and connected by structural ties of the most intimate kind. The sea-fir, moreover, lives colonially, and as an intimately-connected society might be expected to exist —namely, through the apt and regular co-operation

of its various members. By "co-operation" we mean to indicate the act of many individuals, who associate themselves for the purpose of forwarding and promoting any given end. Such a result, however desirable, is not always easy to attain in human existence. For the ways of humanity are often the reverse of bland; and the ambitions of mankind frequently serve to blunt the laudable purpose of working hand in glove and without distinction for the advance of a common cause. In "sea-fir" existence, however, the co-operative principle is plainly and perfectly carried out. Each little mouth, each set of tentacles, and each body-cavity is respectively and together engaged in the work of providing the wherewithal for nutrition. Food is seized and digested within each little body-cavity (*b c*), and is thereafter transferred to the general hollow (*a a*) or interior of the stem and branches, through which the nutrient stream is made to pass to every part of the colony. Each little animal of the society draws its own food-supply from the common stream of nourishment it has helped to form; and co-operation, in the way of a perfect circulatory provision-store, is thus beautifully exemplified in lower animal life.

Thus, a "sea-fir" is essentially a collection of hydra-like animals, bound together in closest intimacy; the individual lives of the colony merging in the life of the entire organism, the colony being maintained through individual effort, and the individual life being in turn dependent on the connected existence of the colony. But the further question of the origin and manner of growth of such a colony yet remains to be discussed. How does such a colony of animals arise, and in virtue of what processes does the "sea-fir" come to differ so materially from the single and simple animals of higher life? To answer these queries, let us return to our hydra for a single moment. We observed that animal to produce "buds" (Fig. 1) which grew into young hydræ, and which remained connected to their parent for a certain period, but ultimately disengaged themselves from the parent stem, and sought a new sphere of life for themselves. During the attached period of these young hydræ, however, we noted that the body-cavities of the young and the parent were in full communication. These latter facts thus show us—firstly, that the hydra, through budding, converts itself from a "simple" to a "compound" animal; and, secondly, that in respect of the full connection between its attached young and itself, it may be strictly compared to the "sea-fir." So that, in plain language, we discover a "sea-fir" to be a hydra-like animal, which has budded like the familiar denizen of our pools, but which differs from hydra in retaining its buds permanently and as stable parts of the organism. The justice and exactness of this comparison are, of course, clearly seen when we discover that each little animal of the "sea-fir" is modelled exactly on the type of the hydra. Is there, however, any further proof that the colony or compound animal we term a "sea-fir" is simply a kind of hydra which has produced permanent "buds?" The reply to this question will be clear if we study for a moment the process of growth which has made the "sea-fir" what it is.

From certain receptacles (Fig. 7, A, B, C), which are developed in due course on the branches of the "sea-fir," true eggs are discharged into the surrounding water. Like our hydra, this animal colony therefore possesses the power of reproducing its race by means of eggs; whilst it also makes good the constant loss and death of its own component parts and beings by the process of budding, to which it owes its form. Each egg of the "sea-fir," or neighbour zoophyte (Fig. 7, D) at first swims freely in the surrounding water, but ultimately discards its moving existence, and settling down (Fig. 7, E), develops a bud-like projection (Fig. 7, F), which grows into the form of a single little hydra-like animal (Fig. 7, G). This single organism is, in fact, the founder of the colony (Fig. 7, H); for, in the case of sea-fir development, as soon as its hydra-like features are fully formed it begins to bud. These buds remain permanently connected to the primitive organism, and in turn produce other beings like themselves; so that in due time, and by this process of "continuous" budding, we have the form of the tree-like "sea-fir" reproduced. Thus the history of the "sea-fir," from first to last, teaches us that it is really a hydra-like organism, which, through the permanency of its buds, has become a colonial animal, and which has had its "way of life" marvellously adapted to its compound nature. Whilst conversely the hydra

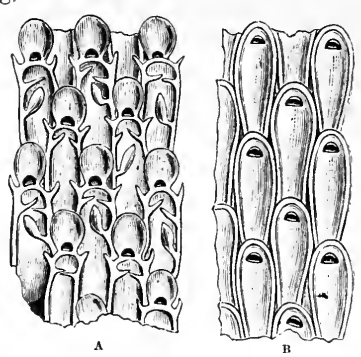


Fig. 5.—Cells of Flustra avicularia (A), and of Flustra carbasea (B).

illustrates a primitive form, which might perhaps be regarded as possessing no stability in respect of its buds, and which therefore only temporarily and feebly imitates the colonial nature of its nearest kith and kin.

A very few words will dispose of the "sea-mat" which we also found growing to the oyster-shell, and which, on examination by the microscope, also reveals to us a compound or colonial animal. Here, however, a structure of a higher kind awaits our investigation. Each little animal of the sea-mat is enclosed, like a little prisoner, in a "cell" (Fig. 5) of its own, and there is an utter lack of the harmonious and co-operative relations we saw to exist between the animals of the sea-fir colony. Like the sturdy smith in the "Fair Maid of Perth," each member of the sea-mat (Fig. 6) colony fights, in the struggle for existence, "for its ain hand;" and probably, when we discover that it possesses a higher structure than the sea-fir animal, we may admit that there is less need for co-operation than in the latter case.

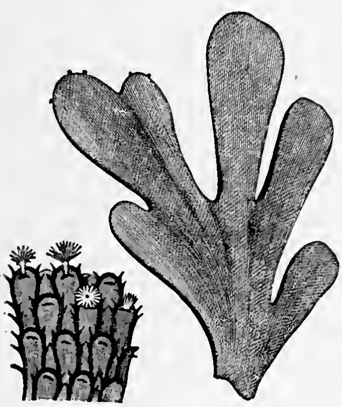


Fig. 6.—Fragment of Sea-Mat (*Flustra*). Life size and magnified.

Within each cell of the sea-mat we find a complete digestive apparatus, a nervous system, and other belongings of the animal constitution at large, and with such provision for their wants, the sea-mat animals can well afford to assert an air of semi-independence of each other. There are differences to be thus descried in the ways of lower existence as in colonies and societies of men. Possibly, were our knowledge of the phases of lower life more complete, we should find that the causes which have operated in producing dependence in the parts of one animal, and independence in those of another, are more nearly related to the ways of humanity than might be supposed to be possible. The sea-mat grows to its compound estate, as does the sea-fir, by a process of continuous budding from a primitively single being, arising itself from an egg. The results of the budding process in the sea-mat are surprising in respect of the numbers of cells and tenants produced. On both sides of the leafy organism the cells are packed as thickly as paving-stones in a street—so thickly, indeed, that it is evident that the results of human over-crowding are unknown in these lower spheres of animal existence.

Last of all, some readers may feel inclined to ask, "What relationship can be shown to exist between these animal colonies and the single and simple animals around them?" A pertinent and important query this, and one to be briefly answered. A dog, a bird, an oyster, or an insect, are each and all single animals—or, as we term them in zoology, *individuals*. Now what, it may be asked, is the criterion of an animal's "individuality?" We reply, the fact that in itself it represents the *total development of a single egg*. Whatever the single egg may and does become, that is the true "individual." Judged by this standard, the dog, bird, oyster, insect, and all higher, as well as many lower, animals are true "individuals." Now apply this reasoning to the hydra, and to the sea-fir or sea-mat. From what does each of these three organisms arise? From a single egg (Fig. 7). That single egg becomes in the sea-mat and sea-fir a colony, numbering its members by thousands. Therefore

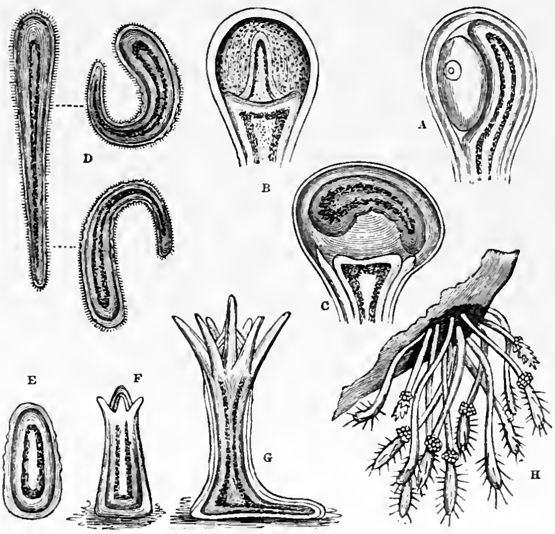


Fig. 7.—Development of Zoophyte (Clava squamata). *After Allman.*

the whole colony corresponds to the "individual" dog, insect, or oyster of higher life. And what of the hydra? At first single, it appears to represent in itself the "individual." But we know that it will bud throughout the summer, and that its buds will drop off, and produce buds in their turn, with a similar result. Here, therefore, again, we say that the hydra and all its detached buds and their generations form the "individual;" for the animal and its scattered progeny represent simply the

complete development of a single egg. So much for the individuality of animals. The hydra has led us far from its humble self in this scientific ramble: but the digression may not have proved altogether uninteresting, and may besides serve to show how topics of commonplace kind may lead to larger fields of thought, or may even enable us to scale the heights of a loftier philosophy.

COLOUR-BLINDNESS.

BY GRANT ALLEN, B.A., AUTHOR OF "THE COLOUR SENSE," ETC.

A SMALL boy of nine years old, a pupil at a Belgian primary school, was playing one morning with his school-fellows, when some accident or other led him to talk about the blueness of the tongue. The boys around, taking the remark for a joke, began at once to laugh incessantly. But little Delbœuf—now a learned Professor in the University of Liége—persisted with all seriousness in his assertion. "What," he cried out energetically, "do you mean to tell me that your lips and your tongues are not blue? Do you mean to say that Eugene here hasn't got blue cheeks?" And he pointed in triumphant confirmation to the very reddest and rosiest of his companions. "Blue!" shouted all the other boys in astonishment; "red, you mean." Little Delbœuf was overwhelmed by the authority of others; yet he felt internally convinced that the tongue and the cheeks had for him precisely the same colour which he knew in other instances as blue. Going home, he inquired of his family, and found that they corroborated the strange statement of his school-fellows. There was only one solution of the difficulty: his eyes must evidently be differently constructed from those of ordinary people. In short, he was colour-blind.

The peculiarity to which the very inaccurate name of colour-blindness is generally given was first noticed by the celebrated chemist Dalton, himself one of the sufferers. He happened once to examine the blossom of a *Geranium zonale*, which has really violet petals, by the light of a candle. The flower, which seemed to him blue by daylight, became unexpectedly red when looked at under this artificial illumination. Dalton called the attention of others to the strange phenomenon: but to his surprise they saw the blossom as violet as ever. The incident led him to make a critical study of his own colour-perceptions, and he soon learned that they differed in a striking and very definite manner from those of normally constituted persons. Since that time, numerous observations have been published upon this interesting question, but those of Professor Delbœuf are at once the latest and the most scientific.

Whether such a thing as absolute colour-blindness—that is to say, total inability to distinguish any one colour from another—ever actually occurs in the human eye is very doubtful. At any rate, most so-called colour-blind persons do really distinguish certain colours, and only confuse certain others in a definite order. In ordinary cases, red is the hue which is least perceived, and it is confounded with green. Thus, M. Delbœuf cannot distinguish rosy-cheeked apples upon a tree from the foliage which surrounds them, nor can he perceive any difference between the blossoms of a Japanese pear (*Pyrus japonica*) and the neighbouring leaves. As a rule, only two colours are really recognised by such persons, and all others are referred to one of these two. Most people call them blue and yellow; but, as we shall see hereafter, it is wiser not to give them the names of any special hues known to normal eyes. Dr. Wm. Pole, who is another sufferer from this defect of vision, has given me the following diagram of the solar spectrum as it appears to normal eyes and to his own (Fig. 1). It will be seen that Dr. Pole rightly abstains from identifying either of the two colours which he perceives with those discriminated by ordinary people, calling them only Colour A and Colour B.

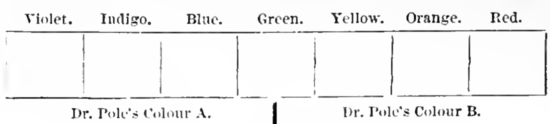


Fig. 1.—Comparison of a Normal and Abnormal Eye.

Since it is not true, therefore, that these persons are absolutely colour-blind, it is usual on the Continent to speak of them as Daltonists, and of their peculiarity as Daltonism. English writers have strongly objected to the use of these terms,

which, they say, tend to make a great man remembered very largely through a personal defect. But on the other hand, no name has ever been substituted for these terms, which does not pervert the real facts, and so convey a false impression to hearers and readers. Accordingly, in this paper we shall generally use these convenient terms, satisfied that Dalton's fame is quite able to take care of itself in other ways, and that it is better to be remembered for having discovered an interesting defect, than to be forgotten for want of ingenuity in perceiving its true nature.

M. Delbœuf made most of his observations in conjunction with a friend, M. Spring, whose eyes were normal. They began by heating a platinum thread in a Bunsen lamp, and examining its spectrum by means of the spectroscope. Platinum heated in this manner yields a light which, when decomposed by a prism, shows belts of colour almost resembling those of the ray of sunlight. To make the comparison easy, a graduated scale (Fig. 2) was projected upon the spectrum; and one of its divisions was always brought to the same portion of the image. For this purpose, the fixed dark and bright lines of the spectrum * offer a simple means of uniformity; and the experimenters settled that the number 180 should always coincide with the bright yellow band of sodium.

All being properly arranged, the eye of an ordinary person saw the colours as represented in Fig. 2. The luminous belt extended from division

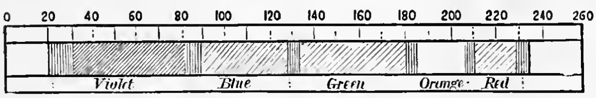


Fig. 2.—Platinum Spectrum seen by Normal Eye.

20 to about division 235; but these limits are subject to variation, in accordance with the intensity of the light and the state of the particular eye. The violet seems to end and the blue to begin between 80 and 90. The vague points at which the colours merge into one another are shown in Fig. 2 by the upright lines; while the slanting lines show the parts where they are tolerably uniform. Yellow is not marked in the diagram, because it occurs only in a very small patch of the platinum spectrum, on the line of the sodium. The brightest part of the belt is in the orange; and the shading of the diagram roughly represents the relative brilliancy of the other colours. It will be noticed that the blue end is particularly wanting in brightness.

* "Science for All," Vol. II., p. 126.

When M. Delbœuf himself, however, came to examine the spectrum, he found that it yielded him a very different result, which is represented in Fig. 3. The spectrum did not extend so far for his eyes as for those of his friend; he saw nothing at

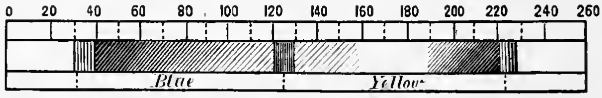


Fig. 3.—Platinum Spectrum as seen by Colour-Blind Eye.

the extreme ends, where M. Spring saw the darkest violet and the darkest red. Midway between these points he saw two colours only, merging into one another about division 123, or very nearly at the same point where blue merges into green for normal eyes. M. Delbœuf calls the two colours which he can distinguish "blue" and "yellow"; but Dr. Pole is doubtless safer in calling them A and B. To eyes thus constituted, it is clear that all red, orange, yellow, and green things will appear nearly alike: the only difference between them will be one of greater or less brilliancy, not one of colour properly so-called.

Nevertheless, Daltonists manage very cleverly to use the same language as other people, and to apply it on the whole with extraordinary correctness. They learn that bricks are called red, that grass is called green, and that buttercups are called yellow; and they soon make these distinctions in speaking between the various shades of their "colour B." Daltonists are generally acutely sensitive to slight variations in the intensity of light, or in its varying shades; just as the blind are acutely sensitive to minute differences in touch, on the principle commonly, though incorrectly, known as compensation. Whenever one set of ordinary senses is denied us, we are compelled to make more diligent use of the remainder, in order to keep up with our fellows; and so people who cannot distinguish all the usual colours have to pay special attention to light and shade. In this way many Daltonists never suspect their own deficiency, because they are enabled by long practice to employ the same language as those who possess normal sight. But there are certain employments in which Daltonism is a great drawback; as, for example, amongst pilots and railway servants. A man who only distinguishes a red danger signal from a green caution signal by some slight diversity of brightness is much more likely to help on a collision, than a man who sees red and green as extremely unlike colours. Accordingly, the discovery of such an abnormality as Daltonism

may be made a means of averting untold calamities by land and by sea. For this purpose many railway companies carefully examine all persons seeking employment in their service, and never admit them if there is any suspicion of Daltonism. The number of persons found to be thus affected is something truly astounding to those who have always looked upon the perception of colour as a common and universal inheritance of our race. M. Favre has calculated that in France alone there are no less than three million Daltonists; while Dr. Stilling places the proportion throughout Western Europe generally at 5 per cent. From experiments with 3,080 negroes, Dr. Swan Burnett, of Washington, found that 1·6 per cent. of the males and 0·11 per cent. of the females were colour-blind. It would therefore appear that the Africans are less subject to this optical deficiency than Europeans.

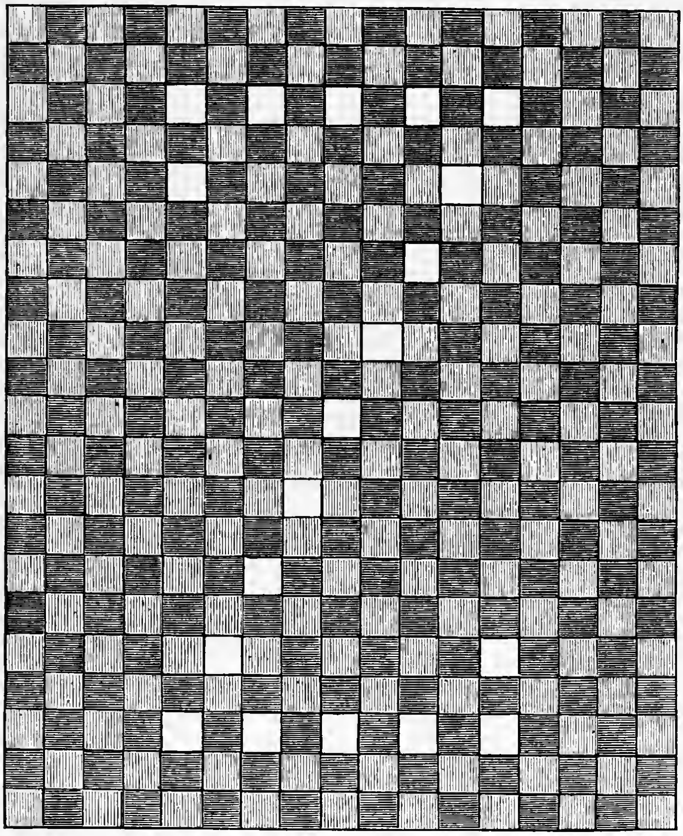


Fig. 4.—Table for Detecting Colour-Blindness.

It is not easy, however, to discover whether a particular person is or is not a Daltonist. An intelligent man, accustomed to hear objects described in correct colour terms, learns to apply these with so much accuracy that even a scientific cross-examination often fails to confuse or convict him. The slightest difference in shade or texture will enable him to match pieces of coloured silk or paper, which seem identical in all but hue to ordinary eyes. Dr. Stilling has therefore invented an ingenious kind of test for settling the question in the case of railway servants, with whom aberrations on such a subject are so very undesirable. He has constructed a set of coloured plates, consisting of little alternate squares, bounded by black lines, each of which contains a letter of the alphabet, or, for the benefit of those who do not read, a conventional figure such as a cross. One of these plates is represented in Fig. 4. The squares with upright lines are coloured dark green in the original, while those with horizontal lines are coloured a much lighter green, thus making a sort of shepherd's plaid pattern. The squares left blank in the figure, however, are coloured in the original with a shade of red exactly equal in intensity to the lighter green, and they form a letter of the alphabet —in this case Z. Any person with normal eyes who looks at the tables can at once distinguish these red letters; but they utterly baffle the Daltonist. If the colours were not divided by black lines, the point where they overlapped might enable a sharp eye to detect the difference; and if all the green squares were of one shade, the red would very probably betray itself by some slight variation in intensity, quite inappreciable to ordinary eyes; but Dr. Stilling's precautions are so thorough that no Daltonist ever escapes detection by their means; indeed, many persons who never suspected themselves of the smallest deficiency are often shown in this manner to be slightly affected with Daltonism.

Stilling's tables also prove that there are many intermediate stages between the most acute colour perception and absolute Daltonism. Just as some musical ears can detect differences of pitch as minute as one sixty-fourth of a tone, while others can detect only a semitone, and extremely unmusical persons cannot even distinguish any two notes in the same octave, so some eyes instantly perceive the red letters on the tables, others notice

them after a little inspection, and others see them only after they have been pointed out, or not at all.

Can anything be done to correct this defect? Professor Delbœuf has invented an ingenious process for temporarily effecting this purpose. By interposing a transparent purple substance between the eye of a Daltonist and the objects viewed, he finds that they suddenly acquire, if not the normal colours, at least certain colours which the Daltonist has never before seen. In order that the amount of the purple substance should exactly suit the particular eye, he constructed a wedge-shaped glass vessel (Fig. 5), with a graduated scale. This was

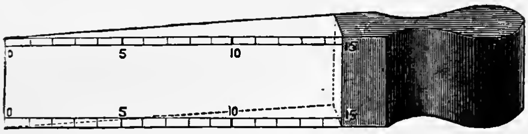


Fig. 5.—Vessel for Correcting Daltonism.

then filled with a solution of purple fuchsine, and moved up and down between the eye and the platinum spectrum, till the proper thickness of liquid for producing the desired effect was found. At once Professor Delbœuf discovered that the red, the violet, and the other colours which he usually confused, had assumed a totally distinct appearance; while scarlet, which generally seemed to him dull and dingy, shone out with a perfectly astounding and dazzling brilliancy. In all probability, for the first time in his life, he *saw* red as other people see it. Experiments on other Daltonists soon showed him that they were similarly affected by the fuchsine, and that when they had found the proper thickness of a particular solution they could always readily distinguish colours which they had hitherto invariably confounded. Nature suddenly acquired new charms, and clothed itself with a marvellous variety of unknown tints.

On the other hand, M. Delbœuf found that by exactly reversing this process he could produce an artificial Daltonism in normal eyes. A solution of chloride of nickel, which is green, placed in the same vessel, and graduated by means of the scale so as to suit the particular eye, reduced the colours of the spectrum to two, or at most three—blue, green, and yellow. The red, the orange, and the violet disappeared, and the world probably assumed for awhile the same hues which it always presents to the Daltonist. Everything seemed to be either blue or yellow. For this reason M. Delbœuf is very possibly right in assuming that those colours are really seen by Daltonists as by other people.

What is the cause of these peculiarities? Fully to answer that question would draw us off too far into the region of mere guess-work, for we know too little about the machinery of sight to be able as yet to account for such special facts as those of Daltonism. But we may get a fairly good idea of the case if we suppose that in the Daltonist eye the green rays of light have an excessive influence, while the red and violet rays have too little influence. The green, in other words, seems to produce so much effect that it drowns the other colours, just as a big drum drowns the notes of a small musical instrument in its neighbourhood. If so, we might expect to restore the natural balance by stopping a part of the green rays. This is just what the fuchsine does; it lets through the red and the violet, which by their union form purple; but it checks the larger part of the green. Then, for the first time in the Daltonist eye, the red and violet rays are able to act unimpeded, the blue and yellow retain their natural colour, and the central green is separately distinguished. The chloride of nickel, on the contrary, acts in precisely the opposite manner. It checks the red and violet rays, allowing the green, and to a less extent the blue and yellow rays, to pass through. Thus the two former colours become so enfeebled that they no longer affect the eye, which is accordingly brought into somewhat the same condition as that of a Daltonist.

By examining each person with the solution of fuchsine in such an instrument as that in Fig. 5, it would be possible to discover the exact extent to which his eyes required rectifying, and so to construct purple spectacles of the necessary thickness. A liquid like the fuchsine solution would be an awkward substance, it is true, for such a purpose, but there can be little doubt, since attention has been so fully directed to the subject, that some means of colouring glass in the needful manner will soon be invented, and that colour-blindness will be practically obviated, just as short and long sight have already been corrected by the different kinds of spectacles. Even with the liquid alone Professor Delbœuf exclaims that the whole world has taken a new and enchanting aspect in his eyes. Shut out before from all the enjoyment of that wealth of colour which renders nature so beautiful to our sight, he can now behold, he says, the bright clusters of the red horse chestnut throw themselves out in vivid masses on the sombre verdure of the foliage; the rich blossoms of the rhododendron change as by miracle from a uniform blue to their

natural crimson and violet; and the berries of the mountain ash, which seemed before like black spots against the green leaves, take in a moment the semblance of glowing bunches. If only these results could be obtained with a solid, colour-blindness might practically become a thing of the past.

OCEANIC ISLANDS AND THEIR HISTORY.

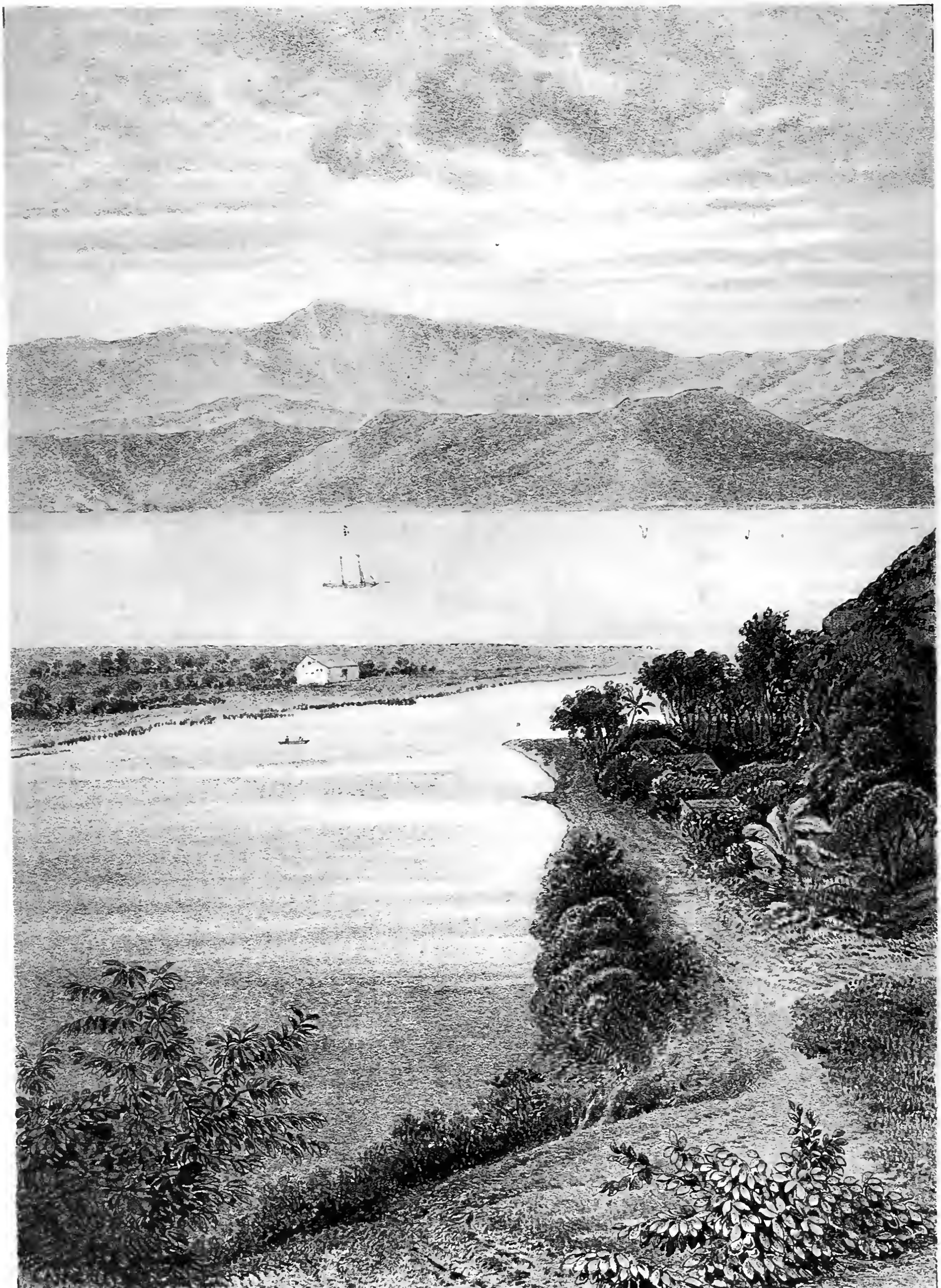
By Professor P. Martin Duncan, M.B., F.R.S., F.G.S., etc.

If a very large map of the world is studied, and the spaces occupied by the great oceans are looked at carefully, a considerable number of names will be found printed, in some parts, pretty closely together. They are those of islands; and although the names may be visible enough, the marks denoting the islands are often so small that they can be distinguished only by people who have good sight. Sometimes a very large model of the globe is to be seen, and if it is correct, and if the places marked upon it bear a true relation in point of size to the whole, the greater number of the islands cannot be made visible, and many are only mere points on the surface. The names often occupy a hundred or two of miles, and sometimes a thousand miles, of expanse; but the island itself, perhaps not as large as the Isle of Wight, is a mere dot on the model of the face of nature.

It is rare for any of these ocean-surrounded islands to be of any great size; nevertheless, there are one or two which are of considerable dimensions. They are usually very small, and are either solitary, or in groups of from a few to some hundreds in number. All are in the midst of profoundly deep water, and their distance from the nearest mainland is usually considerable, and sometimes vast. At first sight, the map on which these Oceanic Islands are tolerably largely marked, gives the impression that they are placed here and there without any definite order, and the mind fails to grasp any relation between their position and the mainland. A careful study, however, of the shape of the floor of the ocean, and also of the direction of the trend of some of the great mountain systems of the continents, leads to a different conclusion, and it appears that there is order, in the seeming disorder, of the distribution of these interesting spots on the surface of the globe. One thing strikes every mind, and it is, that these little spots of land surrounded by ocean, most of them remote from land, usually covered with vegetation, and possessing many remarkable animals, should be so isolated by the great depth of water in which they stand. From 10,000 feet to 20,000 feet is a common average depth of the ocean a few miles from the islands; and even when they are in groups, neighbouring islands being not more than eighty to 100 miles apart, there is often deep water between them.

The scientific use of the sounding apparatus has shown that most of these islands are not only surrounded by very deep water, but that their sides are very steep, and that their bases, or the extent covering the sea floor, are small. Many of them rise up suddenly, as it were, and with a most abrupt slope. Many of the islands thus environed by the deep ocean only just rise above its surface, but some have mountains on them, even reaching to the height of as many feet as the sea is deep. High and low hills are commonly noticed upon a vast number of them. The first impulse in endeavouring to learn anything about these interesting Oceanic Islands, is to compare them with the continental islands, which are usually large, and are more or less close to continents, not being separated by very deep water. The distinctions between the two kinds are important. The continental island is constructed, so far as its strata and earth-layers are concerned, upon the same plan as the neighbouring mainland. It is an outlier of the land. Or, if this is not quite the case, the mountains of the coast-line of the continent are in evident relation with those of the island, in their direction and geological age. That these islands once formed a portion of the continent close by, and were separated by marine erosion and some irregular movements of the earth's crust, appears to be most probable.* And this theory is enhanced in its value when it is known that nearly all the animals and plants of the separated lands are of the same species. There is certainly some reason for believing that the period of the separation of the continental island from its nearest mainland, can be appreciated by the resemblance of the plants and animals in both localities. Should nearly all the kinds be similar, and only a few exist, as peculiar to one of

* See "Continental Islands," Vol. II., p. 150.



COAST SCENE ON THE ISLAND OF HAWAII

the land surfaces, the separation may have been very late in the world's history. But if there is a considerable difference in the kinds, and many strange plants and animals are observed, by visitors, from one land to the other, it is assumed that an older date may be given to their disruption. The great similarity of the fauna and flora—that is to say, of the assemblage of animals and of plants—of the mainland and of the continental and sometimes entirely, from those of the nearest mainland, some others, which may be many hundreds of miles from a continent, have many species in common with its surface.

The greater number of Oceanic Islands have a foundation of rock which originated during volcanic action, and they may also consist of coral limestone which has collected around such rocks. Their strata, if they have any, are the result of the wear

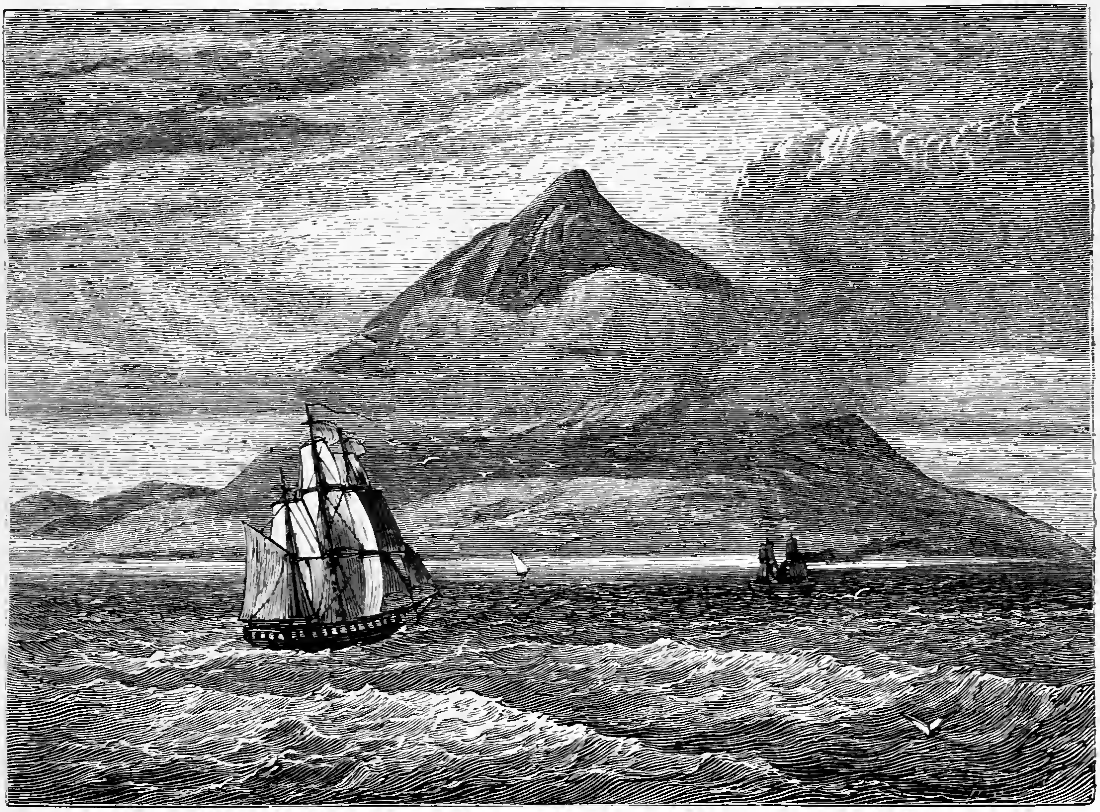


Fig. 1.—Peak of Teneriffe.

island, has to a certain, but arbitrary, extent determined that such and such islands are continental. The Oceanic Island may be, as has been already noticed, not very remote from a continent; but in the great majority of instances there is no geological relation between it and the mainland; the layers of earth are not the same, and the hills are not offshoots, as it were, of those of the continent close by. The exceptions to this statement are not numerous, but there are some important ones; and singularly enough, these exceptional islands partake of the continental character somewhat, and are not perfectly oceanic, as a rule. Again, whilst in some Oceanic Islands the animals and plants differ, partly

and tear, in places, of coral rock, and of the volcanic rock itself; and blown sand is found also. Hence, there is not much diversity in the construction of Oceanic Islands; but their vegetation and animal life are full of novelties to the visitor who for the first time crosses the landless ocean to some of these little paradises. Some are crowded with a luxuriant vegetation, and with birds and insects; on the other hand, others are deserts, bare, inhospitable, and the haunts of seals and a host of fish-loving birds. Some are masses of coral rock with barely a vestige of tree life, and others are steep rocks of basalt covered with guano. In some the precipitous mountains, the volcanoes, and the inland lake or lagoon,

render the flora diverse and charming; and in many, a scanty vegetation struggles for existence against damp, glaciers, gales, and a persistently low temperature.

But before considering this interesting part of the subject, it is necessary to refer to some facts relating to the Oceanic Islands. Consider, firstly, those of the Atlantic Ocean, which are few in number in comparison with those of the Pacific. The Azores come first, and are situated one-third of the way across the Atlantic, west of the Spanish coast, and they constitute a little group of islands, some being a hundred miles apart. Between them there is from 2,100 to 8,400 feet depth of sea, whilst the ocean-floor between their shore and Spain is from 12,000 feet to 15,200 feet below, for the greater part of the distance. On the west of the Azores the water is shallower for 300 or 400 miles, than to the east; it is over 12,000 feet deep between them and the Oceanic Island of Madeira to the south-east; but to the north the depth is about 6,000 and 7,200 feet. These islands, far out at sea in the midst of a deep ocean, are, when the soundings are more carefully examined on all sides and are compared with those of the whole breadth of the Atlantic, on a gentle rise of the ocean floor, which is about 1,000 miles across, and which extends from Iceland to about the latitude of the West India islands, but about one-third of the way across to the African coast. This sub-marine ridge is slight, but it divides the Atlantic there into an eastern and western trough, and the depth of water on it varies from 6,000 to over 11,000 feet. All the rocks of the Azores rising from this ridge are of a volcanic nature, and, indeed, evidences of volcanic eruptions of late date are to be seen. Moreover, the mountain-peak of the island of Pico is a most symmetrical extinct volcano, 7,613 feet in height above the sea.

Thus, this heap of volcanic rocks in the deep sea, with a great mountain on it, rests on the ridge, and is separated by very deep water from the European, African, and American coasts; the temperature of the sea on the floor being very low.

If the ocean be sounded from the Azores to the south-east, after a certain distance the depth increases, and instead of bottom being found at 6,000 feet, it requires 12,000 to 15,600 feet of line to reach it. This part of the ocean floor is in the eastern trough of the Atlantic; but it is narrow, and the water becomes shallower pretty close to the island of Madeira, which is towards the northern extremity of a sub-marine plateau which slopes from the coast of Portugal, being a little more deeply placed than the great central ridge. The water is as deep as ever between Madeira and the neighbouring coast of Africa, and therefore it is in the position of an Oceanic Island. Moreover, it is formed of volcanic rocks, but there are the relics of sedimentary strata which collected when there was an old Madeira, equally volcanic, and in the Miocene age, and they contain corals and plants of that remote time. Indeed, the evidence goes to show that even then the island was oceanic, but that the climate and other conditions of the Atlantic, generally speaking, were different.

Standing up from deep water in the sea, the island rises above sea-level to 6,000 feet, and is remarkable for its rugged surface, great precipices, as well as for some plants and land-shells which are peculiar to it and which will be noticed farther on.

South of Madeira, but separated by very deep water, are the Canaries, a group of islands surrounded by deep water except on the African side, two of them being near the coast. They are volcanic, and the high Peak of Teneriffe (Fig. 1), towering thousands of feet, is a grand instance of a volcano. Still to the south are the Cape de Verde Islands, separated from Africa by a sea under 12,000 feet deep, but surrounded everywhere else by water resting on a floor deeper down than 14,000 feet. They are volcanic, and several islands have mountains on them of 7,000 to 9,000 feet, and St. Vincent's highest point is probably 2,483 feet.

Before considering an important set of islands off the American coast, and which differ to a certain extent from all these, it is not unprofitable to endeavour to imagine how these four groups of islands would look, were the Atlantic drained off. There would be a vast flat with a table-land in the centre rising very gradually, and almost imperceptibly, to the height of 6,000 feet in some places, and 12,000 in others; and rising suddenly from the extreme height would be the precipitous crag of the Azores, with others close by towering up another 9,000 feet. So that from the western basin of the Atlantic, or rather from its floor, the rise would be 23,400 feet, but in so many miles that it would almost be imperceptible. Farther east, and especially in the Canaries, the craggy mountains would be as high as the highest of the Himalayas, and in the remote distance the table-land of the African continent would commence. On the opposite side, the Bermudas, about to be noticed, would appear to rise more suddenly, but not to so great a height as

the others. All this leads to the impression of the isolation of the islands, and their great separation from the mainland and from each other. And when it is considered that they are surrounded by a sea very cold below, warm above, and which cannot wear away the rocks at a depth of a great many fathoms, the manner in which these mountains, more or less submerged (for such are the islands), came to be, is difficult to explain.

Another group of islands, oceanic in character, is on the American side of the Atlantic Ocean, and several degrees to the south. Deep water surrounds these Bermudas on all sides, and the sounding-line plunges down, within a few miles of the shore, to 10,800 feet and then to about 14,400 feet. Seven miles to the north of the islands, the depth of the sea is 5,180 feet, and two miles farther off 10,650 feet, and to the north-west there is 12,000 feet of depth seven miles from the land. Hence the Bermudas rise, remote from land, very suddenly and steeply from the deep ocean floor, and are not situated upon a ridge. The absolute amount of land above the sea on the Bermudas is 12,000 acres, but the shallow water, around in a circle, of which the land forms a part, is twenty-four miles long and twelve miles wide. No volcanic rock is visible; on the contrary, the land is of a white granular limestone covered with blown sand, and there is much red earth. The shallow sea around the land is covered with coral, and all these islands and shallow sea-floors are composed of carbonate of lime, the result of the vital activity of the white coral polypes.

From observations made with some care, it appears that formerly there was more land than there is now about the Bermudas. Now, the Azores and the Bermudas are two types of the commonest oceanic islands—those which are purely volcanic, and those which are formed of coral rock—and in the one the island is piling up every now and then by the casting forth of volcanic matters and their collection on its surface; and in the other the area of the land is diminishing, for the island has sunken slightly.

Not many miles north of the equator, 540 miles from South America and almost due south of the Azores, midway between Africa and South America, are some very small rocks, called St. Paul's, rather under a quarter of a mile from end to end. Some are low and dark coloured, and others, from fifty to sixty feet above the sea, are precipitous, excessively rugged, with channels and straits through which the sea dashes. Birds make homes of the rocks, and instead of the splendid foliage of the Azores and Bermudas there is a desert. So sheer are the sides of these rocky islets, that ships find 600 feet of water at a distance of 100 yards from the land. From this depth there is a rapid increase, and there is very deep water all around this little speck in the ocean, and it is deepest towards the nearest land, which is Brazil, to the south-west. Thus 16,656 feet of depth occur not far off in this direction, and it increases 1,200 feet more within a little distance; but to the north-east there is not 12,000 feet of water. The reason is that these rocks, forming a third kind of oceanic island, are on the edge of the continuation of the central ridge of the Atlantic floor, which slants in this part of the world to the south-east from north-west. The rock is not a recent volcanic one, nor is it a coral rock, but it belongs to an ancient form of volcanic rock, and there is reason to believe that this little group of islands with vast depths around them have a great ancestry. Certainly they are worn away year by year by the rush of the sea, and the guano of the birds decomposes the rock also.

There is a perpetual swell on, and the current on the surface of the ocean is so strong that a boat can hardly be pulled against it, for it rushes along by the sides of the rocks like a mill-race. Isolated indeed are these rocks.

There is deep water to the south-west of St. Paul's Rocks, and before the islands and rocks of Fernando Noronha are reached, there is a depth of 14,780 feet. Within six miles of this small group of rocks and islands, there is a depth of 6,060 feet, so that they rise abruptly from the sea-floor, and not from the central ridge, but from a tongue of slightly elevated sea bottom which reaches towards Cape Roque, the nearest point, on the South American coast, distant nearly 200 miles. This tongue of floor is in deeper water than that remarkable, long, mid-oceanic floor-rise. The island is of volcanic rock called phonolite, from its giving a musical sound to the stroke of the hammer, and there is sandstone; and one of the peaks, the relic of a vast former one, is 2,000 feet in height. A fine vegetation covers much of the island, but not much is known of it, although enough has been gleaned to be of use in appreciating the relation of the flora of this island to that of the mainland.

A glance at the map of the world will show the St. Helena and Ascension Islands, and these are situated in moderately deep water, but on the continuation of the mid-Atlantic ridge.

Far to the south, 1,320 miles from St. Helena, and 1,550 miles almost due west from the Cape of Good Hope, and a third farther from the extremity of the American continent, is a group of islands oceanic in the extreme. One is the island of Tristan d'Acunha, and the others are called Nightingale and Inaccessible Islands, Gough Island being 200 miles to the south of them. They are not on the ridge, but on the other side of some deeper water, and on a vast submerged plateau at least 12,000 feet deep, which is an extension of the sea-floor of the Antarctic Ocean. Standing in this deep water, there are two decided currents in the sea which washes their shores—one from the American side, or the Cape Horn, and the other a part of the Brazilian current, which runs to the south from that coast. They are small islands, and Tristan d'Acunha is about four miles long and as many broad, or sixteen square miles in all, the highest peak being 8,326 feet above sea-level. Nightingale Island is twenty and a half miles off, and its area is a square mile; while Inaccessible Island is four square miles in area, and is about twenty-three miles from Tristan. The whole group consists of volcanic rocks, and the peak of the last-mentioned island is a rounded, tipped, conical mountain, and of volcanic origin. It is tolerably evident that these remote islands of the Atlantic are not without a definite relation to submarine ridges and plateaux, and that although their coasts have been worn, there is no proof that of late years there has been any great diminution of their size.

The occurrence of the islands on the central Atlantic ridge is very suggestive of the question which bears on the origin of the islands—Was that long, sinuous, broad submarine sounding ever nearer the surface than it is now, or above it? And, indeed, the whole subject of Oceanic Islands teems with problems relating to former continents and lost lands continuous more or less with those now existing.

These questions receive a greater importance when the natural history products of the islands are considered. The Azores, Madeira, Teneriffe, and the Cape Verde Islands were, when first discovered, resplendent with flowers and magnificent vegetation. Whence did this come? Later investigators have shown that Madeira contains a considerable number of kinds of animals, or molluscs, which, living on land like the snail, are called land-shells. A lizard of a kind like a gecko is found in this last-mentioned island and in the Cape Verde Islands. Moreover, the scientific examination of the botany of the islands proves that whilst many plants of the same kind are found in all, and also on the neighbouring continent, a certain number are peculiar to the islands. The plants of the Azores may be taken as the example. Those which have not been introduced by man, may be divided into three sets. Firstly, there are kinds which are also found in South-western Europe. Secondly, a most suggestive and remarkable set of about thirty-six in number are found also in Madeira and the Canaries, but nowhere else. This constitutes a little Atlantic oceanic island flora. Finally, there are forty flowering plants in the Azores which are peculiar to those remote and isolated spots of land. Thus, there are plants and a gecko common to the islands; plants common to them and the continent; and shells, insects, birds, and plants, not found anywhere else on the globe except on these Atlantic islets. Whence came these things which can neither swim nor fly? The answer will account for the Oceanic Island.

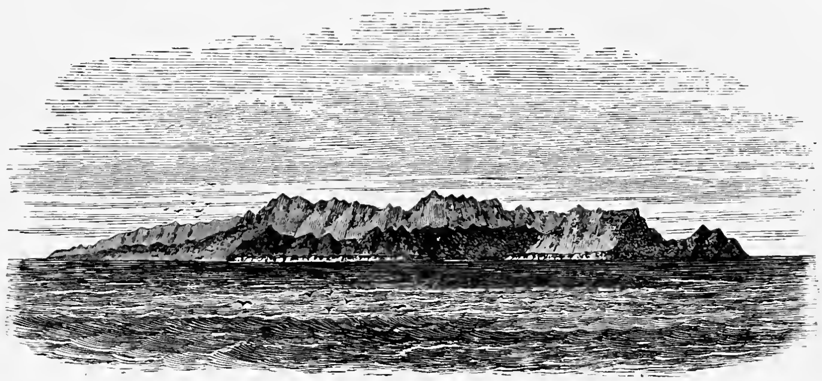


Fig. 2.—Santa Christina (*Marquesas Islands*).

The usual answer is, that these living things were specially created for the islands; another is that these volcanic islands have been planted by waifs and strays from the continent and from one another, and that the insular position and surrounding conditions enabled the plants to alter in their kinds. The first method is of course possible, but it is against the analogy of nature, and the very improbable second may have had something to do with the occurrence of kinds not known anywhere else. There is another alternative which will develop itself gradually as these pages progress.

It is necessary to consider, however, the nature and bearings of the plants and animals of some of the other islands. In noticing the plants of Fernando Noronha there are some extraordinary instances of very wide distribution to be observed, and it may be stated here that there are many kinds of animals which live in South America which have great anatomical and natural history resemblances to others in Africa.

The plants of Fernando Noronha are allied to those of South America, and there is amongst them a common convolvulus, which is known also in the West India Islands, as well as in the Cape Verde Islands on the other side of the Atlantic. There is no special assemblage of plants peculiar to the island, but there is a peculiar species of fig tree. Two lizards occur, but not the lizard of Teneriffe; one is of a kind found in South America, and the other is peculiar to the island.

In the southern group of the Atlantic oceanic islands, there are not many kinds of plants, but Tristan d'Acunha and its neighbouring island, contain plants the majority of which are of South American (Fuegian) kinds. Other plants are of genera which have kinds at the Cape of Good Hope, and a pretty pelargonium is very representative of the African kinds. Two very common plants are found also at Amsterdam Island, 3,000 miles distant, and one plant is of a genus only found in America and in those islands. Clearly no seeds could have got all this way by sea or by birds.

Fig. 3.—Tahiti (*Georgian Islands*).

In the Indian Ocean and the great waste of waters to the south, there are not very many Oceanic Islands. To the east of the continental island of Madagascar there are the well-known islands of the Mauritius, Bourbon, Rodriguez, and to the north of them some so-called "banks," where the land rises just out of water, being encircled with coral reefs and made up of coral limestone. Far to the south, on a line with these, are the Crozets, a little group of islands volcanic in structure, and this linear direction is over a space equalling that from the North Cape of Europe to Constantinople. There is about from 6,000 to 10,000 feet of water in the sea separating these

islands, but it is much deeper between Bourbon and the Crozets than to the north. To the east of these islands, just to the north of the equator, and near Cape Comorin, are the Laccadive and Maldive Islands, which, made up of coral like the Bermudas, are as an archipelago, 470 miles long and 87 miles broad, and they rise up from the ocean floor from a great depth and suddenly. Hundreds of islands of all sizes are found amongst them, and most consist of a ring of land broken by the surf outside and having a shallow lake or lagoon within. Now, to the south of these is a vast shallow, called the Chagos Bank, some 76 miles long, 24 to 60 feet deep at the edges, and 300 feet in the middle, and all around it is very deep water. Far to the south are St. Paul's and Amsterdam Islands, and still further Kerguelen's Land. A third set of islands situated in a north and south direction, but, of course, like those just mentioned, widely separated, is to be traced from the Bay of Bengal, where the Andaman Islands have the Nicobars and Keeling Island in linear series. Thus, in this great ocean, the Oceanic Islands widely separate, and consisting mainly of coral formation—there being the Atlantic type of volcanic island far to the south—are in linear series, and were the sea drained off they would represent three distant parallel sets of high peaks—a crowd of mountains, here and there separated by plains and shallow depressions, but on the whole they would not be so high as those of the Atlantic.

In the Pacific the Oceanic Island is seen to perfection; there are many hundreds there, now grouped together, now separate, now low, now often constituting very high ground, and always surrounded by very deep water, 12,000 feet being a common and average depth. It is usual to consider New Zealand amongst them, and New Caledonia also, but they are very exceptional, and are more or less semi-continental—for although they are separated from the nearest mainland by great depths, they are composed of rocks most of which are to be found in Australia. It is not proposed to refer to them, but to those islands which crowd the map as minute specks on the ocean from Japan and Australia to the Americas over a vast surface of the globe. These islands, sparingly distributed to the east—for they are rare indeed for 60° of longitude from the American coast—are in great abundance to the west, and form a great number of archipelagoes or assemblages of islands in groups, separated by deep sea from others.

The Sandwich Island group is the most northerly, and consists of several islands, the most celebrated being Mauna Loa, with its vast volcano rising up to 14,000 feet, the whole standing in water of at least 12,000 feet. Measured from N.W. to S.E., the group is at least 530 miles long, and Dana states that there are lines of rock and reef which carry on this array of peaks 2,000 miles, or "as far as from New York to Salt Lake City." There is, however, a great ocean space to the south-west of the Sandwich Islands, and then there is a crowd of islands. Now these, under a great variety of names, such as the Ladrone, Caroline, Friendly, Fiji, Navigators, Georgians (Fig. 2), and Marquesas (Fig. 3), form a vast series, ending in the remote south-east at Easter Island. They are not placed without order, for it can be shown that the main trend of these Oceanic Islands is in parallel lines directed on the surface of the globe from north-west to south-east nearly.

This so-called trend, or bearing with regard to the compass, or this geographical distribution, so to speak, of the Oceanic Islands of the Pacific, is certainly true regarding the great majority. It is most suggestive when considered in relation to the less manifest but still decidedly orderly position of the Atlantic islands. Moreover, there appears to be much truth in another observation, which we owe to the distinguished American, Dana: it is that the space of sea between the long parallel lines of the islands, of which the Sandwich group form the northerly, and the Tahiti and all the rest just alluded to are the southerly, is nearly without any islands. He reminds geographers also, that the low-shored and flat islands are immediately on either side of this landless space, and that the remotest islands to the north and south have high land and are mountainous. Nearly all the lower islands resemble the Bermudas, in being composed of coral limestone, and in being surrounded by coral reefs. They may be eighty miles long, or not half a mile, and if there is not a high central mountain there is a still lagoon or lake, into which the sea passes. The mountain, when it exists, is invariably composed of volcanic substances, such as basalt, and traces of small pieces of this mineral, in the form of low pinnacles or small rocks, are occasionally seen sticking out of the coral rock when there is no hill. Where the island is low and has a lagoon, it is, of course, a more or less perfect ring-shaped spot of land, and in many there is vegetation close to the beach, and often a line of planted cocoa-nut trees. In the larger islands there is more vegetation, and in

the mountainous ones it is profuse. Now, these Pacific islands, ranged in a more or less orderly manner in parallel lines, separated by a vast landless space of sea, occupy more than 6,000 miles (or one quarter of the globe's circumference) in length, and 2,500 in breadth. They are remote from each other in many instances; they are far off the American continent, and nearer but still distant from the Asiatic and Australian landmasses. They have no mammals on them, but birds abound, and there are a few reptiles in some. Now, these birds strike the traveller at once, and can be readily divided into those which have great powers of flight, and could fly from one island to another, and from the nearest continent; and into those which cannot fly far, and which live on fruit or the products of forest land. It is not surprising to recognise in some of these distant islands some of the wandering birds, but there is no mistaking the interest excited by discovering that a great number of these land birds are peculiar to some of the islands, and are not found anywhere else. They are, therefore, what are called endemic kinds. Now, if the vegetation is examined, some trees which have been introduced by man from distant lands will be noticed; some plants are the same as those of the nearest mainland of Asia or America, but the rest are peculiar. Some of them are endemic, and are not found elsewhere on the globe, and the rest are trees which are known as shrubs elsewhere. Just, then, as in the Atlantic Oceanic Islands, there are plants which are found on the neighbouring continent, and a peculiar flora also characteristic of some of the islands, and endemic, so in the Pacific there is a corresponding arrangement. The plants of the two sets of islands are, however, not the same. It must be remembered that whilst some seeds travel far with the wind, and may be wafted by tide and currents, others, and the majority, cannot be thus distributed. Salt water is very destructive to things living on land and in fresh water. Moreover, in addition to this peculiar vegetation, some of these islands have fresh-water shell-fish belonging to the same genera as those so common on the great continents. Another point of interest in the relation of the living things of these islands to those of the continent, is the fact that in some very remote ones, such as the Galapagos Islands, which are nearer the American coast than any others, being distant from it about 500 or 600 miles, there are not only a very considerable number of kinds of birds and plants which are endemic, but there are peculiar lizards and also huge tortoises which are essentially land-loving creatures. Now, the endemic plants and birds of these islands, although of different kinds to those of the nearest continent, still resemble those of South America; but the tortoises, gigantic in size and formerly vast in numbers, are totally unlike anything on the mainland of America, or on any of the other islands in the Pacific. The only spot on the earth where similar tortoises—that is to say, of the same huge dimensions and presenting nearly the same anatomical peculiarities—were found, are the islands of the Aldabra, Rodriguez and Bourbon group, to the east of Madagascar, on the other side of the globe. These largest of tortoises are island dwellers, and are gradually being exterminated by the wicked waste of man.

How these tortoises came to be on such distant spots surrounded by the sea, how the land-plants, humming and other birds, the fresh-water shell-fish, and the lizards, endemic or not, came to exist on these widely-scattered Oceanic Islands, is a great mystery. Some kinds of birds and plants may have been carried by wind and wave, but other causes must have been in action to permit of the existence of the floral beauties of Selkirk's Island—Juan Fernandez — or of Fiji, or of Hawaii. It may be mentioned, for it adds to the grandeur of the question, that not only is there a resemblance of the kinds of fresh-water living things and of some animals and plants of South America and Africa, but that there is a resemblance of New Zealand and South American kinds also. Moreover, the plants of the south-west of Australia are in some instances closely resembling those of the Cape of Good Hope. It is quite evident that most of the animals and plants of Oceanic Islands, and most of those which are found widely separated in very distant countries, could only have got from place to place on dry land, or by fresh-water streams.

It is quite impossible that gigantic tortoises, lizards, hosts of insects, which can neither swim nor fly far (or at all), and fresh-water clam-shells, could get on to islands remote from land and surrounded by deep sea by chance, as waifs and strays. And at the present day we do not find the plants of countries or of the Oceanic Islands changing or being added to by the natural introduction of those hitherto unknown on them. It is not consistent with the analogy of nature, nor with the first principles of science, to believe that every one of the thousands of Oceanic Islands has had its plants and insects, animals, birds, and shell-fish, especially

created and placed on it. There must be some more comprehensive method, and it relates to those grand causes which produced the Oceanic Islands. In the Pacific Ocean the long trend of islands from near Japan to Easter Island is, for the most part, on a line of less depth than the central landless space to the north and east of it. The depth may be said to average from 12,000 feet to 15,000 feet, and that of the space from 15,000 feet to 18,000 feet. Again, to the north of the space there is the line of the Sandwich Island group in its fullest extension. This is over a sea-floor whose depth is about that of the much longer line to the south, and there is deeper water farther north. If the map of the Pacific Ocean were shaded to represent the profoundest depths, and these remarkable sub-marine elevations of a few thousand feet, the marking would start from the southern point of South America, and would be carried on to Japan; to the north of the equator there would be a parallel line. On these sub-marine ridges are the Oceanic Islands, as a rule, and they are more or less of volcanic origin. Dana, in noticing the great number of islands in a small space in the Fiji group, was impressed with the truth of Charles Darwin's great theory that the coral island and the other islands with reefs around them at some little distance, were formed during the gradual sinking down of the more or less submerged mountain on which the coral grew. The hill-top sank under the waves and the coral grew upwards; and, in the instance of the low-lying islands, the hill has disappeared and the coral has persisted. The Fiji Islands now constitute about 5,500 square miles of land, and Dana shows pretty conclusively that before they sank as mountains the sea washed the shores of 15,000 square miles of land there. The sinking of the ocean floor carrying with it the bases of the mountains, and the submergence of their summits, are grand phenomena which have attended the formation of coral reefs and islets of circular form. Moreover, the deep valleys of the mountains which still exist above the level of the sea, open at once into deep water as if the hill-sides scored by age had been submerged. But what was there before this submergence took place? The trend of the islands and of the submarine ridges bears a very curious relation to the trend of the mountains of the west of the Americas, and Dana has shown that in the structure of great continents the greater mountain ranges are on a line with the coasts and not in the middle. These considerations lead to the belief that a continent once existed in the position of the present central space, and that the northern and southern parallel groups of islands were once hill-tops of its coast-lines. They are, to use the expression of the great American geologist, memorials over departed lands. It is difficult to believe that hundreds of volcanoes could have built themselves up under water; but there are many proofs that subsidence of the crust of the earth has carried, and does still carry, down mountains. The Oceanic Island of the Pacific is, then, a more or less altered mountain summit, and its endemic and most of the other plants, birds, insects, and shell-fish, are the relics of a drowned land.

In the Atlantic the same line of reasoning suggests the sinking of a former outer Atlantic land — the Atlantis — which was continuous with America and Africa in part. The Oceanic Island is the home of the relics of the fauna and flora of the continent which once supported the mountain whose peaks are now mere points in the ocean waste.

MODERN EXPLOSIVES.

By H. Baden Pritchard, F.C.S., Royal Arsenal, Woolwich.

OLD-FASHIONED people, whose acquaintance with explosives is confined to a knowledge of gunpowder, have been startled by the appearance of late years of a whole army of new-fangled compounds, the names of which are alone sufficient to puzzle any ordinarily constituted mind. Gun-cotton, nitro-glycerine, dynamite, litho-fracteur, cotton-powder, tonite, glonoine, dualine, saxafragine, mataziette, glyoxiline, and blasting gelatine are among the names by which these new explosives have been brought forward; and to those little versed in such matters it seems well-nigh hopeless to attempt to keep pace in one's knowledge with a class of compounds that every day grows more and more extensive. We may know what gun-cotton is, and have a suspicion how nitro-glycerine is made, but beyond this, most people do not go. It appears useless, indeed, to follow the

science of explosives under such circumstances, for no sooner can you become acquainted with the nature and qualities of one than the morrow sees other and more curiously named compounds spring into being. Fortunately, as I shall be able to show in a very few words, the difficulty in understanding all these modern explosives is more apparent than real. Their names, in fact, are the only unintelligible part of them. There is no more mystery about modern explosives than our old friend gunpowder (p. 91, Vol. II.), though perhaps rather less of honesty and straightforwardness. It may be we do not know them quite so well, but at present there are several of the family that require narrow watching to prevent mischief and accident.

To remove the masks, then, from the whole group of modern explosives, it suffices but to say that to all intents and purposes they are one and the same thing. They are "nitro-compounds." Some are liquid, some are solid, some are pure, some mixed with materials that favour combustion, some with materials that retard it, but they are all practically the same. Gun-cotton is a nitro-compound in a solid form; nitro-glycerine is a nitro-compound in a liquid form, and of but these two the whole series I have mentioned consists. Cotton-powder is gun-cotton reduced to a fine state of division; and tonite is the same, with the admixture of a nitrate or similar body; dynamite is clay or other earth saturated with nitro-glycerine; and litho-fracteur, roughly speaking, is the same thing, with a little saltpetre and sulphur added. Dualine is small granules of gun-cotton soaked in nitro-glycerine; and blasting gelatine is not gelatine at all, but nitro-glycerine in which gun-cotton has been dissolved so as to form a sort of jelly. There is a yet more novel explosive compound—the newest of all—which consists of adding to this "gelatine" a further quantity of gun-cotton, making a sort of dough, whose destructive properties seem to combine those of gun-cotton and nitro-glycerine. Glonoine is simply another name for nitro-glycerine; and saxafragine and mataziette are *aliases* for dynamite. So that we really come down to two bodies: namely, gun-cotton and nitro-glycerine; and these may, as I have said, be regarded as the same, with the exception that one is solid and the other liquid.

Being nitro-compounds, they are differently constituted to gunpowder, which, as we know, is a mechanical mixture of charcoal, sulphur, and saltpetre. But all burn or explode something after the same fashion. We know how gunpowder burns. Charcoal and sulphur, which inflame readily enough in air, are consumed much faster if there is an ample supply of oxygen in the neighbourhood. This supply of oxygen is afforded by the saltpetre, which is closely incorporated with the sulphur and charcoal, and hence we get the rapid combustion that is known by the name of an explosion. Nitro-compounds have also a large store of oxygen in their composition to promote violent conflagration, as we shall see at once by following the process of their manufacture.

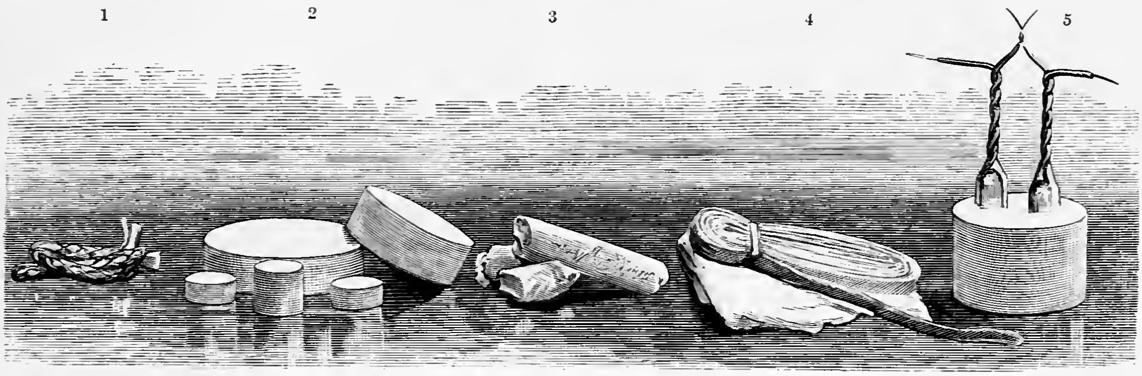


Fig. 1.—Gun-Cotton and Dynamite Cartridges.
1, Slow Match for Firing; 2, Abel Gun-Cotton; 3, Dynamite Cartridges; 4, Gun-Cotton Fabric for Sporting Cartridges; 5, Gun-Cotton Primer, with Detonator fixed ready for Firing by Electricity.

We will take the preparation of gun-cotton to begin with. Schönbein was the first to manufacture gun-cotton in 1846, although the way to the discovery had been paved some years beforehand by the production of a substance analogous to it, in which starch was employed instead of cotton-wool. Cotton of any description may be used, or what chemists term cellulose. Cellulose contains carbon and hydrogen in some quantity; and while the former remains after the

cellulose has been converted into gun-cotton, it is not so with the hydrogen, which is abstracted in the process of conversion, and replaced in the structure by nitrogen. To convert cotton into gun-cotton, or, as chemists say, cellulose into nitro-cellulose, we have simply to immerse the cotton in strong nitric acid. Usually, a mixture of sulphuric acid and nitric acid is made use of in steeping the cotton: the former, which is very greedy of moisture, absorbing all water, and thus maintaining the nitric acid at its full strength, when it does its duty most efficiently. During the time that the cotton remains in the acid bath three equivalents of hydrogen are removed by the oxidising action of the nitric acid, and replaced by three equivalents of nitric peroxide, thus transforming the cotton into what is known by the name of tri-nitro-cellulose. To all appearance, the cotton is the same when it is withdrawn from the bath as when it was put in, but its constitution has quite changed. It is washed in water to cleanse it thoroughly from acid, and may then be stored as it is, or converted into one or other of the compounds we have mentioned.

In the manufacture of nitro-glycerine the same chemical change takes place. In this case you effect the nitrification of a liquid—glycerine. The explosive is simply prepared by mixing glycerine with nitric acid, and then permitting the mixture to drop or fall in a narrow stream into water, when the nitro-glycerine at once separates. Here also the oxidising action of the nitric acid has been such as to remove three equivalents of hydrogen, and to replace them by equivalents of nitric peroxide; and here, too, there is no apparent change in the appearance of the material. Nitro-glycerine as much resembles glycerine as gun-cotton does cotton, and it is only by testing the finished products that they are found to have undergone a thorough change.

The object, in a word, to be attained in the preparation of these explosive nitro-compounds is to secure the proper proportion of oxygen necessary to develop the *maximum* chemical energy by completely burning the carbon and hydrogen present.

Neither gun-cotton nor nitro-glycerine, in the form in which they were first known to chemists, were of little value. The reader may remember to have seen samples of cotton-wool which had been converted into gun-cotton, and which burned with the most ungovernable violence. Gun-cotton wool may even be ignited in contact with gunpowder, and yet not set fire to the latter because of its rapid burning. The military gun-cotton now made use of is, on the contrary, a slow-burning substance (Fig. 1), and unless strongly confined, will not explode with violence when ignited by flame or spark. To "tame" gun-cotton in this fashion was by no means an easy task, and it was only after years of investigation that Prof. Abel, C.B., the well-known chemist of the War Department, succeeded in attaining the desired result. The military gun-cotton is reduced to a pulp, and in this form can be more thoroughly washed and freed from acid (the presence of which renders it particularly unstable), while at the same time the product is easily pressed into any shape afterwards that may be desired. A kind of *papier maché* block is produced of gun-cotton, and in this form the material may be used for blasting, mining, or torpedo work without difficulty (Fig. 1). A slab of this compressed gun-cotton when inflamed, burns freely, but does not explode, and only under certain specific conditions will it ignite with violence. What these conditions are I will presently explain.

Nitro-glycerine owes its application as an explosive mainly to the exertions of a Swedish chemist, Dr. Nobel. This gentleman made a very important discovery in connection with this terrible liquid. He found out there was no necessity for confining it in order to secure a violent explosion. If he could only secure the explosion of a minute quantity, the rest went off as a matter of course. That is to say, by causing a tiny explosion in the neighbourhood of a large charge of nitro-glycerine, he caused the whole to explode, or rather detonate. A small charge of fulminate of mercury, for instance, if made use of for the primary explosion, was sufficient to detonate any nitro-glycerine around it. The result of the explosion, too, was far more violent than that furnished by the explosion of an equal weight of the old explosive gunpowder. A pound of nitro-glycerine when detonated, has been calculated to act as destructively as four or five pounds of gunpowder, but the force is so violent that it cannot always be made use of. Thus in military mining, or for torpedoes, where we desire to develop the most violent and destructive action, nitro-glycerine and its kindred are of the utmost value, but they are useless in fire-arms. In cannon and rifle we want a comparatively slow and weak explosive, and much as we have already done to modify and adapt the new compounds to our use, it has not been possible, so far, to employ either gun-cotton or nitro-glycerine in ordnance or small arms. The nearest approach to a solution of the subject is the construction of cartridges from gun-cotton fabric, which are sometimes

fired from fowling-pieces, and have the advantage of emitting no smoke (Fig. 1).

Notwithstanding its valuable explosive properties, Nobel found nitro-glycerine inconvenient for use. Its liquid form had many drawbacks, and for this reason he cast about for some means of employing it in the form of a solid. This was ultimately accomplished by selecting a spongy kind of clay known as kieselguhr ("flint-froth," p. 343) and simply impregnating it with nitro-glycerine. He got thereby a soft plastic material, which was still very destructive in its action, and which could be handled with ease and effect (Fig. 1). The mass might be pressed into blast holes, no matter how jagged and irregular their form, and could be detonated in the same simple way as nitro-glycerine, that is, by exploding in contact with it a small charge of fulminate powder. No wonder, therefore, that miners and quarrymen became enamoured of the new material; it was plastic, and did not explode by spark or flame like gunpowder, while the violent action of the charge was such, that it required little or no tamping.

Of course a pound of dynamite does not do as much work as a pound of pure nitro-glycerine, and this was one reason why further experiments were made to substitute for the inert mass of clay a body which would contribute something towards the explosion. The pasty material known as lithofracteur, which contains besides a proportion of clay, such things as saltpetre and sulphur, was one of the results of these experiments, and is a substance that appears to find much favour among Australian miners; but, as I have pointed out, all these combinations with nitro-glycerine, no matter what their name, act very like one another. Frequently they differ only in name, and their respective value is in a great measure dependent upon the character of work you want them to do.

Returning once more to gun-cotton, as the material which has been adopted by military authorities in this country to be used whenever other explosive force is desirable than that obtained by gunpowder, there is, we shall find, a great deal to interest us. Our military gun-cotton is the compressed pulp, manufactured on the Abel method, which is pressed into the form of slabs or discs about an inch or so in thickness and a pound, or half a pound, in weight. Tonite and cotton-powder are also forms of gun-cotton that are made in this country and have been successfully used in industrial and mining work, although but little in connection with war purposes; while nitro-glycerine compounds again have been received with some favour abroad by military engineers. But in Great Britain, as I have said, compressed gun-cotton is the chosen companion of gunpowder.

At first, like gunpowder, we used to confine gun-cotton, when firing, in strong cylinders in order to develop its full explosive force, and were careful moreover to maintain the *papier-maché*-like slabs perfectly dry, in which condition the Abel gun-cotton, if it is not explosive, is highly inflammable. Now, however, thanks to the discovery of Mr. E. O. Brown, another clever war chemist, we are in a position to keep our vast stores of gun-cotton in a wet and perfectly uninflammable condition, and can get it, besides, to do its full amount of work without having recourse to costly cylinders wherein to confine it. But I must explain matters here a little, before going further.

The former method of firing gun-cotton was, as I have said, to place it dry, in a strong envelope, and explode it by means of a spark or flame. But it soon turned out that, like nitro-glycerine, gun-cotton could be detonated. A slab of gun-cotton

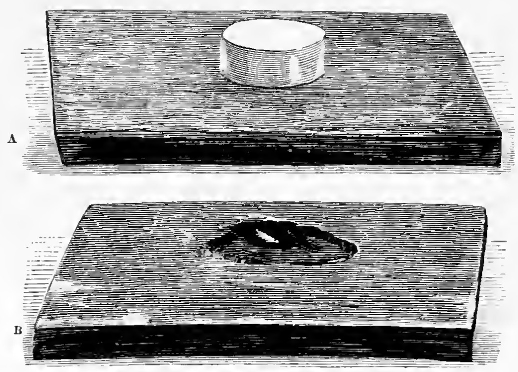


Fig. 2.—Inch Iron Plate, with Gun-Cotton Slab upon it.
(A) Before Firing; (B) After Firing, showing Perforation.

placed upon an iron plate was found to explode with terrible violence, if a few grains of fulminate in a quill tube were put by its side and ignited (Fig. 2). The destructive action, indeed, was the same as if the material was nitro-glycerine and not gun-cotton. So that by simply altering the nature of ignition, we altered also the explosive effect. In fact, compressed gun-cotton turned out in the end to be quite sympathetic in its action; a slab touched by a red hot iron or a flame responded only by burning freely, whereas when ignited by the more violent fulminate, the gun-cotton retorted with similar vehemence.

This particular feature constitutes a great safeguard in dealing with charges of dry gun-cotton, for so long as the material is not strongly confined,

and is not in the neighbourhood of violent explosives of the nature of fulminate, it is a far less dangerous substance than gunpowder. A barrel of gunpowder ignited by spark or flame would not fail to blow down any wall or barrier in contact with it, while a package of gun-cotton would have no such disastrous effect, but simply burn with considerable energy. Only in the event of its being ignited by detonation would the effect be an *explosive* one, and then the result would be many times greater than that of the gunpowder.

But if dry gun-cotton burns vehemently, wet gun-cotton is absolutely uninflammable; and this is what we nowadays employ for military and naval purposes. All our stores of gun-cotton are wet, and thus, its greater safety compared to gunpowder is still more marked. While strict watch and ward must ever be kept over a gunpowder magazine, to prevent spark or flame coming near it, there is no need whatever for such special precautions in respect to wet gun-cotton. Again, gunpowder must be protected as much from damp as from fire, for it at once loses its valuable properties as soon as water gets to it. But the adage, "Keep your powder dry" does not apply to gun-cotton: the wetter it grows, the more uninflammable and safer it becomes, while it detonates just as readily whether it contains thirty or forty per cent. of water or has absorbed but one or two. You might put out a

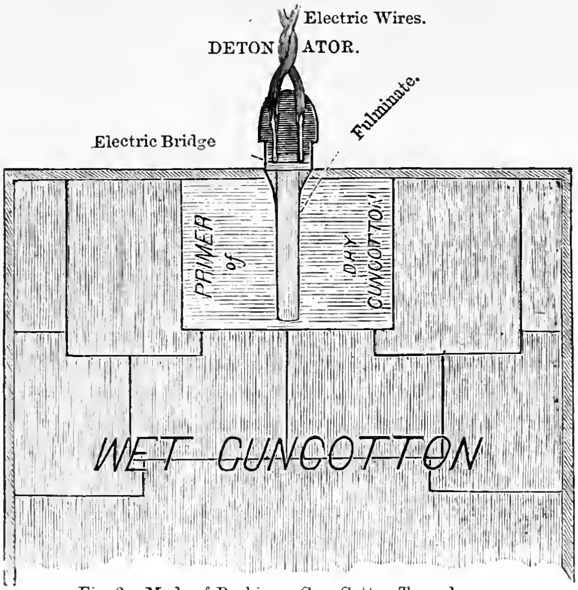


Fig. 3.—Mode of Packing a Gun-Cotton Torpedo.

fire with wet gun-cotton, as you would with a wet blanket, and yet make use of the same material for blowing up a citadel. For this reason it has become invaluable for submarine blasting, and for torpedoes—purposes to which gunpowder, on the other hand, is little suited.

But, it will be asked, how is it possible that gun-cotton reeking with water in this fashion can possibly be exploded. This is Mr. Brown's discovery, to which I previously alluded. The detonation of dry gun-cotton was already an important step, but it was insignificant compared to the solution of the second problem. There is no difficulty in detonating dry gun-cotton, in the manner already pointed out, by means of a quill of fulminate powder; but as soon as the former has absorbed three or four per cent. of water, then this small primary explosion fails to bring about detonation of the gun-cotton. Some other method of securing detonation is therefore necessary, and this was opportunely discovered. In a word, by using an intermediary between the primary charge of fulminate and the wet gun-cotton, the result is at once secured (Fig. 3). The intermediary is a slab of dry gun-cotton termed a "primer." The fulminate, for convenience sake, is usually put in a quill tube, and this quill tube inserted into a hole in the gun-cotton slab, or primer. The quill of fulminate that furnishes the primary explosion is called a detonator, and the detonator fixed into the primer or dry gun-cotton slab causes the latter to explode (Fig. 1). The primer is usually placed in a waterproof bag to keep it dry, and around it is then placed the wet gun-cotton charge. This charge may be of any extent, for so long as some part of it is in contact with the primer, the requisite conditions are fulfilled. The detonator explodes the dry gun-cotton primer, and the dry gun-cotton explodes the wet. So perfectly does the chain of events follow, that it is possible to improvise a torpedo out of a potato-net full of wet gun-cotton; all that is necessary, before casting the net into the sea is, to make sure that the primer and detonator in a little waterproof bag are properly placed in contact with the wet cotton, and then the whole may be detonated with all the force of a modern torpedo.

It matters little how the quill of fulminate, or detonator, is exploded. In the case of moored torpedoes, the ignition is generally brought about by electricity, but a slow match or a quick match may be employed, as also friction or percussion. But a detonator is always indispensable, and when wet gun-cotton is employed, then a primer is also wanted. As only a very small quantity of material is necessary for primers, the bulk of gun-cotton

in this country is kept in a wet, and therefore very safe, state, for only, as I have shown, in the event of a detonator and a primer being in contact with wet gun-cotton, is the latter to be feared.

Its most important application, without doubt, is in torpedoes and submarine mines. The terrible violence of a large charge of gun-cotton exploded under water far outrivals that of gunpowder. A torpedo of 450 lbs. of gun-cotton sunk some distance below the surface, will throw up a cone of water sixty feet in height, having a base of no less than two hundred and twenty feet (Fig. 4). No battle-ship, not even an ironclad, could escape destruction if it came within the limits of this upheaving of water. In fact, it has been pretty well proved that a heavy torpedo of this kind can strike an ironclad mortally if exploded within forty feet of the hull, or, in other words, a cushion of water forty feet in thickness is not sufficient to prevent the explosive force of the gun-cotton from blowing in the iron plating on the sides of a vessel. Gun-cotton is also employed for charging the automatic fish torpedo. This cigar-shaped implement, measuring twelve or fourteen feet in length, which, by reason of the compressed air stored up inside, is capable of running some twenty miles an hour through the water for a considerable distance, carries a charge of compressed gun-cotton in its head. The fish-torpedo is sent on its way to strike an enemy below the water-line, and as soon as the concussion takes place a detonator inside operates, which brings about the explosion of thirty or forty pounds of gun-cotton, a charge sufficient to blow a hole through many inches of iron (Fig. 5). Another kind of torpedo—the spar torpedo—is also charged with gun-cotton. In this case the weapon is carried in a swift steam launch, the charge being affixed to a long spar that protrudes from the bow of the vessel. The launch runs close under the side of an enemy, and as it approaches allows the end of the spar, with the charge of gun-cotton attached, to dip into the water. Submerged in this manner, it is the object of those on board the launch to ignite the gun-cotton as soon as ever it touches the hostile vessel. By means of electric wires in connection with the detonator, this is fired, and explodes the gun-cotton, which, in all probability, blows in the side of the enemy.

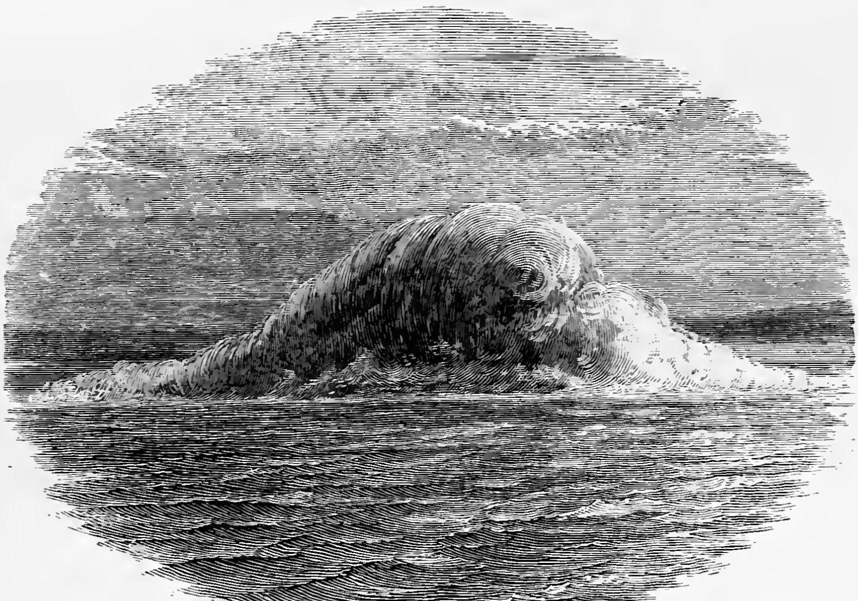
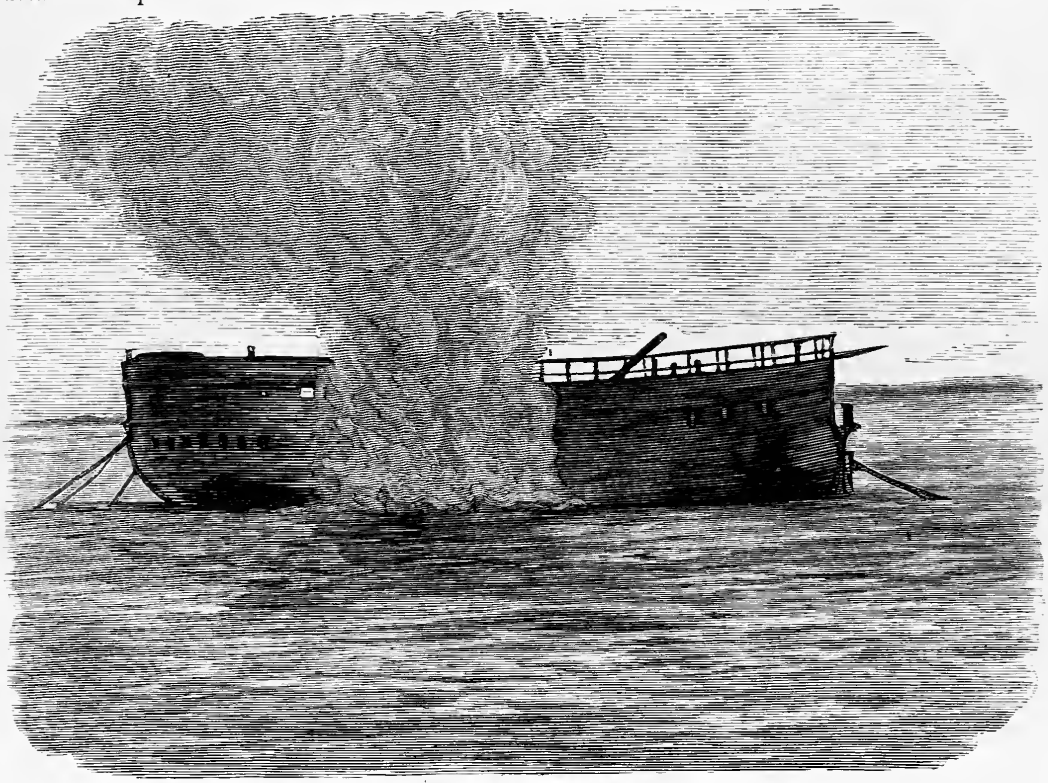


Fig. 4.—Four Hundred and Fifty Pounds of Gun-Cotton Exploding in Forty Feet of Water.
Height of Column of Water, 60 feet: Breadth at base, 220 feet. *(From a Photograph.)*

Gun-cotton also receives important application by our artillery in the form of a water-shell that has been devised by Mr. Abel. This shell is nothing more than a hollow cylinder of iron containing gun-cotton and water. The shell is fired from a gun in the ordinary manner, and at the end of its journey is made to explode through the medium of a detonator inside it. The consequence is a most violent explosion, that scatters the shell

into a thousand fragments. The gun-cotton furnishes the explosive force, and the water distributes that force so equally against all sides of the shell that it is fractured in every direction. As it is the object of shell-firing to break up and scatter the missile as completely as possible, this end is ensured in its entirety by a charge of this description, and hence the water-shell has obtained a murderous reputation equal to that of the dreaded shrapnel.



A WHITEHEAD TORPEDO CHARGED WITH GUN-COTTON STRIKING A SHIP.

In military engineering, gun-cotton has also its place. Not only do our sappers employ the explosive in levelling old fortifications and clearing away dangerous or disused structures, but it is used also for military mining. A crater in the earth is much more readily formed by a charge of gun-cotton than gunpowder, and for counter-mining—or neutralising the mining operations of an enemy—the newer explosive is also more efficacious. In the removal of rocks, whether on land or at sea, gunpowder has long been superseded, as also for the purpose of blowing up wreckage or obstructions in a channel or roadstead. Stockades may be razed to the ground, and trees felled, without difficulty by compressed gun-cotton, which cuts down the heaviest timber as cleanly as with an axe. It merely suffices to place a row of gun-cotton slabs at the foot of a stockade just touching one another, or in the case of a stout tree to string the slabs in the form of necklace and hang it about the base of the trunk, and on the firing of a detonator, the explosive force is communicated instantly from one slab to another. The result is a sharp train of fire that levels any barrier in its vicinity. To show how fast this detonative action travels along a line of gun-cotton slabs, and therefore how instantly the whole charge is fired, I may mention that Mr. Abel has calculated that its speed is second only to that of electricity and light. Detonation along a line of compressed gun-cotton travels from 17,000 to 19,000 feet in a second, or, in other words, at the rate of 200 miles in a minute. So that a train of gun-cotton, reaching from London to Edinburgh, if ignited in the English metropolis, would communicate fire to the terminus in Scotland within the space of two minutes.

The cavalry pioneer is a modern soldier, who owes his being to our new explosives. He must not be confounded with the Prussian Uhlans, that

swept the fair land of France in the last war, and struck terror into the hearts of townsmen and villagers. The task of the Uhlan was to levy contributions and secure stores; the cavalry pioneer tears up rails, cuts bridges, and renders roads impassable. He is well mounted and lightly armed, and selected from his brother troopers by reason of his pluck and daring. The cavalry pioneer carries a belt, in which is packed small charges of gun-cotton or dynamite, and with these he works his mischief. A supply of slow-match and a few detonators complete his equipment, and he should be able to make a dash of twenty or thirty miles into an enemy's country without fear of capture. A slab of gun-cotton that he carries, merely placed upon one of the metals of a railway, and fired by slow-match and detonator, suffices to blow away half-a-dozen feet of rail, and thus render the line unserviceable (Fig. 6). The operation is very quickly performed by a couple of pioneers, one of whom dismounts, while the other holds his horse. The charge is rapidly set upon the rail, the slow-match ignited, and the trooper in his saddle again within sixty seconds. Before he has galloped fifty yards the explosion takes place, and mischief has been done that can be repaired only on the arrival of proper material and skilled labour. Under such circumstances, a daring pioneer might effect his work almost in sight of the enemy. In the same way precisely a telegraph-pole may be cut, and wires and communications broken, in a hostile country by a couple of fearless riders, who have but to draw rein for a moment to effect their object. Light bridges are demolished by the employment of somewhat heavier charges, and a forest-road might be considerably obstructed by the rapid felling of trees across it, by half-a-dozen men amply supplied with charges. Finally, gun-cotton is to be used in future for disabling an enemy's guns, in place of the spike and the armourer's hammer. A small charge thrust into the mouth of a field-piece, or simply wired upon the muzzle, suffices on ignition to break up the weapon, or at any rate so to mutilate it as to render further employment impossible.

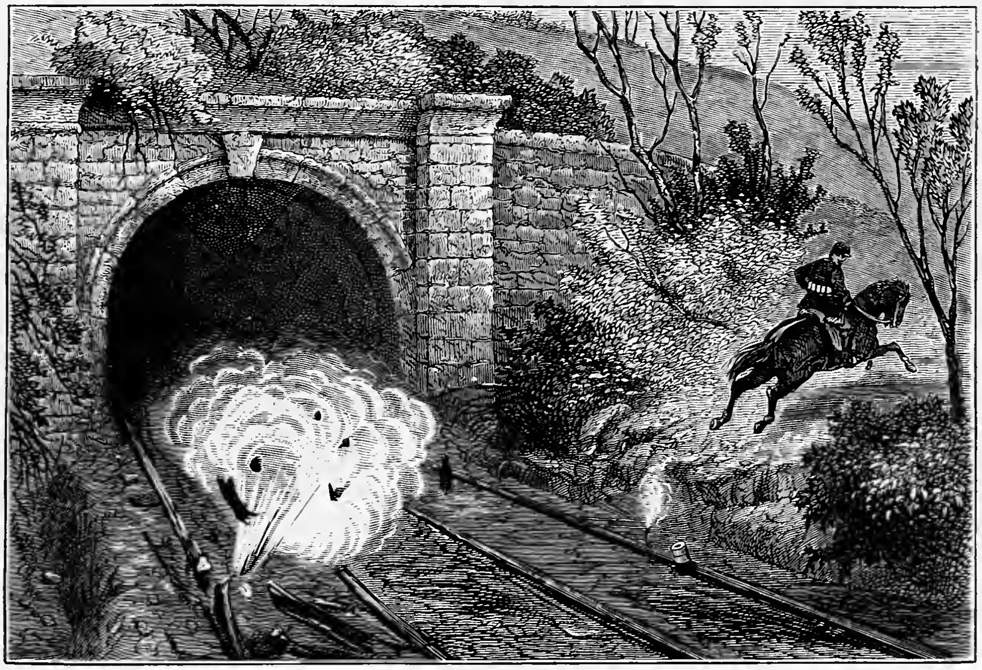


Fig. 6.—Cavalry Pioneer Exploding a Charge of Gun-Cotton upon a Railway.

Thus it will be seen that the new explosives have a distinct rôle of their own. Gun-cotton, I have said, has been chosen by the military authorities in this country from among all these various bodies, and for this reason I have alluded more especially to it. But some of the nitro-glycerine compounds have been found to answer the same purposes equally well; and there are foreign States which prefer to use dynamite where we in England employ compressed gun-cotton. Indeed, for industrial purposes such as blasting and quarrying, the plastic character of dynamite and litho-fracteur is especially useful,

just as, on the other hand, gun-cotton seems to lend itself better for certain military operations. The new explosives are now manufactured in very large quantities both at home and abroad, and several hundred tons of them are yearly consumed. In Great Britain there are two gun-cotton factories, at Faversham and at Stowmarket, besides the Government factory at Waltham Abbey; and one large manufactory of dynamite, and other nitro-glycerine preparations, at Ardeer, in Scotland. On the Continent there are also establishments where both nitro-glycerine and gun-cotton are manufactured, the former in very large quantities. Their employment therefore for military and industrial purposes has become a very substantial fact.

For all this, however, neither gun-cotton nor the nitro-glycerine preparations are likely to supersede gunpowder. The position of that ancient explosive, that has served us so well for centuries past, is, indeed, scarcely affected by the more modern inventions. For fire-arms, rifles as well as heavy cannon, we must still invoke the aid of "villainous saltpetre." We cannot do without it. At the same time it is equally certain that for particular purposes our new explosives are far more effective. Where there is need of great disruptive force, or where there is reason to fear the charge will come into contact with water, or even a moist atmosphere, gun-cotton and nitro-glycerine are decidedly preferable to gunpowder. In a word, each explosive has a part of its own to perform, and it is for the intelligent engineer to select that which fulfils his purpose the best.

THE GRAVEL ON THE GARDEN PATH.

By B. B. Woodward,

Honorary Librarian to the Geologists' Association.

With the return of summer the thoughts of the suburban householder naturally turn to his garden. When the flower-beds have been weeded, and made tidy, and the grass-plot mown and rolled, fresh gravel is strewn on the paths; its bright orange-red colour affording to the eye a pleasant contrast to the fresh yellow-green of the young grass-blades, and the sombre brown-black mould on the flower-beds. Gradually the gravel, by dint of being trodden down and rolled, "binds" together, forming a clean dry path, on which to walk up and down and enjoy the air on a summer's evening. Here only too probably, the interest of the householder in it ceases.

Suppose, however, that we direct our steps to the nearest gravel-heap, or, better still, make our way to a pit whence it is being dug, somewhere, let us say, in the western or south-western suburbs of London—for plenty are to be found there, especially where houses are building and new streets being formed.

Here we shall probably find a section somewhat as follows (Fig. 1). First a foot or so of surface soil on the top. Then several feet of yellowish-brown sandy clay, called "brick-earth." This, as its name denotes, is largely used for brick-making; in consequence of which, it is generally cleared off the land and converted into bricks before any houses are built on the spot. Below this brick-earth is the gravel we have come to see, which here may be as much, perhaps, as fifteen feet thick. We cannot see the base of it, as the section is not continued down to the London clay on which it rests, the workmen being obliged to leave two or more feet at the bottom, owing to the quantity of water contained in it. The presence of this water is due to the rain that falls on the surface and soaks through till it comes to the clay below.

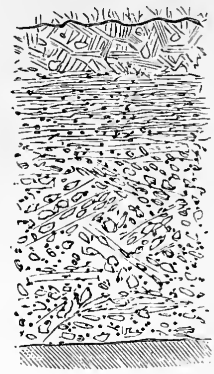


Fig. 1.—Section in a Gravel Pit near London.

Not being able to permeate the clay, the water collects at the bottom of the gravel and filters gradually down the sloping surface of the clay to the river. By leaving, therefore, some of the gravel at the bottom, an efficient natural drainage results; so that houses built on the gravel are, as a rule, drier and healthier than those on the clay. For some time, too, the presence of this water at an easily accessible depth from the surface of the ground, rendered it available as a source of water-supply for domestic

purposes. Hence the reason that the oldest centres of habitation around London are all situated on the gravel.

At first sight, the gravel in the section seems to consist of large and small stones indiscriminately mixed up together. Here and there are some seams of sand inclined at various angles, or sometimes in a horizontal position. A species of arrangement can, however, be made out, when, aided by these seams of sand, a closer inspection is made. By noticing the direction in which the longer axes of the pebbles point, a series of parallel lines or curves can be traced, abruptly terminated by another set of lines or curves inclined at a different angle; these in their turn are terminated by a third set, and so on.

This kind of arrangement, known to geologists as "false bedding," is occasioned by the currents in the waters beneath which they were deposited, aided by the tendency pebbles have in a swift stream to place themselves in slanting positions, sloping up in the direction of the current, as shown in the accompanying cut (Fig. 2).

On turning in the next place to the stones themselves, the advantage of studying them *in situ* becomes apparent, for all the larger stones, from which the most is to be learnt, are sifted out for road-metal, the finer gravel, and the sand, with which the whole is mixed up, being alone used for the garden path.

Fig. 2.—Showing the Position assumed by Pebbles in a Swift Stream.

Nothing can exceed the diversity of shapes and sizes that these stones assume. Some are worn smooth, and are round, oval, or pear-shaped; others are all angles and corners, only the sharp edges being rubbed off. Others, again, are angular; but the corners are considerably rounded, and to these the expression "sub-angular" is applied. In colour, likewise, they vary considerably. Some are black, some nearly white, a few are reddish, but the majority are of a rusty-brown colour, being stained by the iron which the water, percolating through the bed, carries with it in solution. By far the greater number prove, on investigation, to be flints. Of the rest some few are nearly pure quartz, and a good many are "quartzites," or "quartzose sandstones." These two last terms are given to rocks composed of small grains of quartz (*i.e.*, sand) that have either been fused together by heat, or cemented by silica deposited from water. If the grains are loosely connected, it will be a "quartzose sandstone," if closely agglutinated, a "quartzite," or, if very compact indeed, a "quartz-rock."

The questions that then naturally arise to one's mind, are—How are we to account for the presence of the many and various pebbles in this spot? Where did they come from? How did they get here?

The solution of these problems necessitates a temporary adjournment from the gravel-pit, to the side of some little stream, running, let us say, through a limestone country, where the water has cut a glen, or small valley of its own in the limestone, and goes rushing over its rocky bed at the bottom, between the steep banks capped with low cliffs.

Here, if we have read to any purpose the papers that have already appeared in these pages about "Hills, Dales, and Valleys,"* and about "Rivers, and their Work,"† we shall be able to understand what is going on around us, and its bearing on the subject in hand.

On every side the agents of denudation there spoken of are busy plying their work in this quiet nook. The steep slopes on either side are strewn over with the blocks of limestone, large and small, which the rains and frosts have detached from the cliffs above, and which lie slowly crumbling to pieces. Some of these blocks have fallen into the stream, and are there being gradually worn down smaller and smaller. This is effected in two ways: mechanically, by rubbing the pieces together so that they grind each other down; and chemically, since the water, or rather the acid in the water, dissolves the limestone, and carries it off piecemeal in solution.

The first-named process especially takes place in times of flood, after heavy rains, when the swollen stream acquires sufficient force to roll pieces even of a considerable size down with it, towards the sea, grinding them together.

As we proceed down the valley, it widens out; the limestone cliffs receding on either side, till the newly fallen rocks no longer reach our original stream, and the duty of their transportation devolves on the numerous small tributary rivulets that now join it on either hand. Still proceeding downwards, the pebbles dwindling in size as we go, our stream is at length joined by another one of its own size. In this we find that the pebbles are of quite a different kind. Instead of limestone we meet everywhere with sandstone, and were we to

* Vol. I., p. 116. † *Ib.*, p. 208.

trace this stream up to its source, we should find the same process going on there as we noticed in our original one, merely substituting sandstone for limestone. There is another difference, however, of which notice should be taken. Whereas in our limestone stream there was a dearth of sand, and only here and there in the deeper hollows a little reddish mud was lurking, the bed of our new stream shows a great deal of sand mixed with the stones at the bottom. Sandstone is much less easily worn down than limestone, nor can the water dissolve the former and carry it off in solution as it can the latter, so that the small pieces of sandstone that are knocked off remain behind, and are gradually ground down into sand. Following these united streams in their seaward course, we observe how the two sorts of pebbles get intermingled, and on the whole dwindle in size, especially the limestones, whilst sand and mud become more plentiful. A third stream soon joins them, containing, likely enough, yet other pebbles, and the whole process is again repeated; the stones being slowly swept down the valley till the lower ground is reached, and the river becomes too sluggish to transport them farther.

Another important agent in moving stones down stream is ice. When the streams are frozen over, the pebbles near the banks frequently get embedded in the ice, which on breaking up floats down the stream, dropping its burden as it melts.

These pebbles, or gravel, as they would collectively be called, together with the sand and mud that we have been watching in their progress down the stream, are nothing more than the chips and shavings, so to speak, on the floor of Nature's great workshop, where she is busily employed in slowly, but surely, remodelling and altering the hills, dales, and valleys, around us. Not that they are wasted: she wastes nothing. The greater part of them, as we have already learnt,* ultimately find their way to the sea, there to be spread out on the bottom and made into new land ready for use when the present shall be worn out.

Such being the case, can we attribute a like origin to the stones in our gravel-pit? can we show that they are derived from the different strata over which the Thames flows? were they brought here by that river? and if so, why are they so far removed from its influence?

The beds around London consist of sands, clays, pebble-beds, or gravel, and chalk. The ideal quarry we visited some little time back† is a sort of diagrammatic epitome of these beds, which, with the exception of the two top ones, *i* and *k*, contain, as we saw, few hard materials save flints. It is, therefore, easy to understand that a stream running over rocks such as these would speedily wash away the softer materials and carry them off to sea, leaving only the obdurate flints behind in the valley. Flints, moreover, being amongst the hardest of stones, are not easily worn down, nor can they be dissolved by the water; consequently, if they are derived from the strata around they ought to be readily recognised by any such peculiarities of form, &c., as they exhibited in their parent beds. That such is actually the case you may readily see for yourself.

The smooth round black pebbles can surely have come only from one of the old sea-beaches, either bed *d* or *g*. The most angular forms, but slightly stained with iron, were probably obtained directly from the chalk.‡ The sub-angular varieties may be traced either to the "drift" beds (*i* and *k*) or to the gravel beds overlying the London clay, and not shown in the quarry; but of these more anon. Careful search will almost certainly result in the discovery of one of the green-coated flints from bed *b*. The quartzites, with a few exceptions, come from the drift beds, whither they were brought from long distances far north. They boast a much more ancient pedigree than the flints. Torn from their parent rocks, they were rolled and rounded on some old sea-shore in Triassic times,§ were covered by other deposits hundreds of feet thick; were consolidated together, upheaved and brought to light again, to become once more the victims of denuding agencies, that finally in the shape of ice transported them to the Thames Valley, and left them with other débris in the glacial series.

Whilst these far-travelled quartzites are abundant in our gravel, any fragments of the oolitic limestones that form the upper part of the basin of the Thames are rarely to be met with, the water dissolving them apparently long before they reach thus far down the river.

To enumerate all the stones in the gravel, and to sketch their history, is not our intention. It is sufficient for our purpose to show, by quoting the commoner ones, that our surmise as to their origin is correct.

Were any further proof wanted that these stones

* "Science for All," Vol. I., p. 118. † Vol. I., p. 65.

‡ Of course all the flints were *originally* derived from the chalk. Many interesting examples of chalk fossils—sponges, casts of sea urchins, &c.—may be obtained in a gravel-pit.

§ See FRONTISPIECE to "Science for All," Vol. I.

were brought here by the river, it would be furnished by the shells of fresh-water molluscs, specifically identical with those now living in the Thames, which have been found in places amongst the gravel.

In places, too, the bones of the animals that roamed on its banks have been dug up. The mammoth or hairy elephant, the hairy rhinoceros, the reindeer, the musk ox, were among the winter visitants, their places in the summer season being taken by another elephant, the wild horse, lion, bear, hyæna, and even the hippopotamus. Remains of the last-named animal have been found as far north even as Yorkshire.* That man was present also, the stone implements of his manufacture attest.

In the older beds of gravel these consist of rudely-chipped flints; but in the newer beds the stone axes, "celts" as they are sometimes called, made out of hard volcanic rocks by the laborious process of grinding one stone against another, clearly show an advance in civilisation. These implements, prevalent in most river gravels, and in many caverns, are of the same types as those found in the Danish kitchen middens.†

Having established the point that this gravel was brought hither by the river, we must now endeavour to ascertain why the river no longer flows over this spot. A glance at a geological map will soon show that the gravel in our pit is part of a continuous layer stretching from the river's mouth up to Maidenhead, and extending for a greater or less distance inland from either bank. Furthermore, if the map show the contour lines, that is to say, lines formed by joining together all the points on the surface of the ground that are the same height (generally 10 ft., 20 ft., &c.) above high-water mark, the fact becomes apparent that these gravels are at different heights above the level of the river. Thus Wimbledon Common, Clapham Common, and Barnes Common are covered by gravels each at a different level one below the other, like steps in a staircase. These steps or terraces are the result of the erosive action of the river working in two ways,—firstly in a vertical direction downwards, deepening the valley, and secondly in a horizontal direction, cutting laterally into the sides of the valley as it zigzags across it. This last method will be best explained by referring to the annexed diagram (Fig. 3).

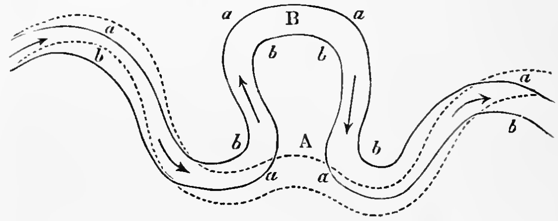


Fig. 3.—Showing how a River gradually shifts its Bed.

The current of the stream (shown by the arrows) striking against the banks at the points marked *a*, *a*, *a*, gradually wears them away whilst a corresponding silting up goes on at the opposite points marked *b*, *b*, *b*. Where the river, meeting with some obstruction, takes a large sweep and winds back again upon itself, as at the point A, a new channel will in course of time be formed there, the old one at B will be silted up, and after a time the river would occupy somewhat the position indicated by the dotted lines. And so on.

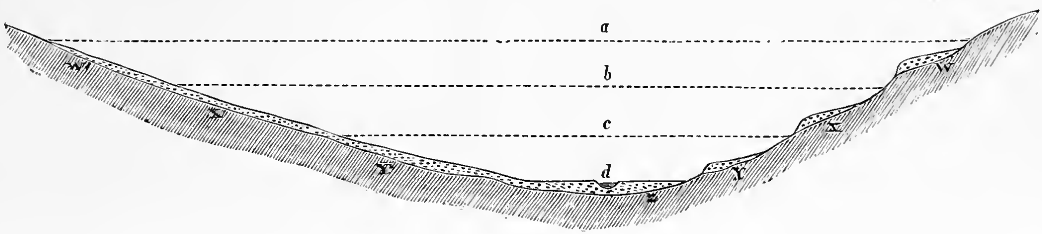


Fig. 4.—Diagrammatic Section Across a River Valley to show the Formation of Terraces of Gravel at the Sides of the Valley.

Bearing this double erosive action in mind, it follows that as the valley gets deeper and deeper, so the river flows at successively lower and lower levels, and in its meandering course cuts back the very beds of gravel it had formerly deposited. Thus in Fig. 4, which represents a diagrammatic section across a river valley, the river at first flows at the level indicated by the dotted line *a*, strewing its course with gravel and sand. Gradually it cuts its way down to the level marked *b*, and working through its old gravel beds, leaves only the patches W, W′, on either side of its valley. Still cutting its way down, the lower levels, *c* and *d*, are successively

* See "Science for All," Vol. I., p. 288. † Vol. II., p. 102.

reached, and the same phenomena repeated (x, y). A series of terraces, or, more generally, patches of gravel, are thus left behind one above the other on the slope of the valley. The closer the river ran to its base, the steeper the terrace became. These terraces are, of course, not continuous all along the river-valley; nor are they always to be found one above another in close proximity, as represented on the right hand of our diagram; sometimes one out of the series in a river-valley will be wanting at a given spot, sometimes another. Frequently, too, some of them will merge into each other and form a continuous layer, as shown on the left-hand side of our diagram (w′, x′, y′). Though originally deposited beneath the water, these terraces are now left high above it, and it is in just such an old terrace of gravel that our pit has been dug.

The brick-earth on the top is a tranquil water deposit, and was laid down when the water no longer covered the gravel save in times of flood. The swollen river overflowed its banks, spread over the flats around, and on returning left a coating of sandy mud behind, in precisely the same manner as it now, after a season of heavy rain, floods the low-lying lands on either bank, leaving on its departure a layer, a few inches thick, of unsavoury black mud.

At the time when these old gravels were deposited, the land doubtless stood at a higher elevation above the sea; the climate was colder; the rainfall greater, and consequently the river far larger, more powerful and more liable to floods than at the present day.

Since—as we trust is by this time clearly shown—there exists so close a relationship between the stones of a river gravel and the rocks over which that river flows, and in which it has cut its valley, it follows that whilst, on the one hand, a knowledge of the different kinds of rock present in any given catchment basin will enable one to judge pretty accurately what the nature of the river gravels will be, an inspection of the gravel-beds of a river will, on the other hand, furnish a tolerable clue to the kinds of rock one may expect to find in the area it drains.

In those districts where mineral veins are plentiful, fragments of the ores, if not liable to decomposition in water, will be obtained from the beds of the streams.

A familiar instance of this is to be met with in Cornwall, where the gullies and water-courses abound in places with what is known as "stream-tin"—that is to say, pieces of tin-ore. These rolled fragments can readily be traced to the veins of that metal in the rocks through which the stream has cut its way. Numerous stream-tin works have been established in the county for washing the gravels and picking out the pieces of ore. The process is less expensive than mining or quarrying the "lodes," and the results are generally most satisfactory to the fortunate owner.

Tin being pretty widely distributed over the world, it is frequently found in the alluvial soils of rivers, and new works are constantly being started in different quarters of the globe. One of the latest recorded is in the Malay Peninsula.

Nine-tenths of the gold of the world, we are told (p. 73), is obtained by washing the alluvial soils of rivers (the "drift" of the gold-digger, and not to be confounded with the "drift" of the geologist). "Weathered" out of the quartz-reefs, the little bits of gold were washed down the valley by the stream and dropped in its channel as the velocity of the current abated. Proportionately heavier than the rest of the detritus with which it was associated, it sank soonest, and is therefore found more abundantly at the base of the "drift" and next to the "bottom rock."

Iron is present in nearly all gravels in the form of oxide of iron—iron-rust—staining the pebbles, and sometimes cementing the stones and sand into hard masses.

Precious stones are likewise largely obtained from river gravels. Sapphires and diamonds are found associated with the stream-tin in the river-valleys of New South Wales. The diamond is commonly met with in the auriferous "drifts" in Russia, Brazil, and Australia, as well as in the river-gravels of South Africa. Isolated and rolled crystals of the ruby are present in the river-beds of Ceylon and Siam. The less precious agates, in all their varieties, such as carnelian, chalcedony, onyx, &c., are extremely abundant in many river channels where the stream runs through a district in which volcanic rocks are present. So likewise are their close relations, the jaspers.

Hitherto we have spoken only of gravels that have been formed in fresh water, but large deposits both have been, and are forming at the present day on the coast and under the sea. The fragments of which they are in this case composed, being derived from the neighbouring cliffs, and ground down by the waves on the beach. The softer materials are carried out to sea, and deposited as mud in deep water. Next in order, proceeding shorewards come the sands, which are the result of the attrition of the gravel, then the shingle, and

finally the beach. The gradual transition from the coarse débris on the beach down to the sand at low water mark is often very prettily displayed, as for instance at Freshwater Bay, in the Isle of Wight, where it is impossible to tell when one ends and the other begins.

Marine pebble beds in course of formation at the present day are usually termed "shingle" in distinction to the fresh-water gravel; but geologists apply the name "gravel" to both indiscriminately, when they occur in the geological series. Thus this term is applied to those beds of pebbles and sand in the glacial drifts that are spread over the greater part of England to a depth in places of more than 40 ft., and which, as we have already shown (Vol. I., p. 69), were deposited under marine conditions.

Another old marine gravel of earlier date is that from which many, if not most of the sub-angular flints in our gravel-pit came. Its position is directly above the London clay, and patches of it are to be seen on the tops of the hills at Hampstead, at Harrow, at places in Essex, and capping the high ground near Aldershot and Bagshot, from which latter place it takes its name. The position of these isolated patches shows that it formerly spread over the greater part of the Thames Valley below Reading. As these beds were of considerable thickness, and the traces left of them are small indeed, compared to the quantity worn away, the amount of denudation through which they have passed must have been enormous.

Below the London clay, again, there are some more marine pebble, or gravel beds. Two are represented in the quarry section (*d* and *g*). Of this age, also, is the well-known Hertfordshire pudding-stone, in which the sand and stones have become so firmly cemented together, that when struck with a hammer it breaks in pieces through pebbles and all, as though it were one solid mass. A rock of this description is in geological parlance called a "conglomerate;" were the pebbles angular instead of round, it would be a "breccia."

As we run our eye down the succeeding strata in the geological table, "conglomerates" and "breccias" come in ever and anon; but the oldest yet known are those lately described in the Precambrian rocks of South Wales.

Just as the stones in the fresh-water gravels furnish a clue to the rocks in the river basin, so the pebbles in the marine ones give a hint as to the probable nature of the coast-line whence they were derived, and the student of past changes on the surface of the globe looks to the old pebble-beds, conglomerates, and breccias for aid in reconstructing as nearly as may be the distribution of land and sea that obtained at the different periods of the world's history.

Both conditions of formation are of interest to all intelligent people, inasmuch as they evince the gradual way in which changes in the shape of the land proceed or evolve, so to speak, under our very eyes. Both tell the same story concerning the economy of Nature, and the indestructibility of matter; deposition and reconstruction going on in one spot, simultaneously and in proportion to the amount of waste and denudation that takes place at another.

A PEAT-BOG.

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PEAT-BOGS, peat-mosses, turf-moors, and turbaries, are flat marshy areas in which a long-continued growth of water-plants has formed a rotten mass of soft black material, having a generally level surface, with or without green vegetation. They are met with in many countries, mostly in the temperate and sub-arctic zones, but some in warmer latitudes, as the "Dismal Swamp" in Virginia and North Carolina. Within the tropics decomposition goes on too quickly to allow of the accumulation of successive generations of plants.

When cut into, in the process of digging peat, such a bog or moss as we meet with so extensively in Ireland, for instance, is seen to consist of—(1) An uppermost brownish layer of roots and fibres, light and loose in texture, easily dug out in square sods, and soon dried in the air as "turf" for fuel; (2) below this is a moister, denser, and blacker mass of decomposed plants, somewhat like rotten wood, but still fibrous enough to hold together when dug out with the peat-spades, in long square clods ("long squares"), to be stacked and dried; and

this passes downwards into (3) either a hard, bituminous, coal-like peat, or into a black sludge, which, after having been scooped out and dried on the ground, can be cross-cut into cubical blocks fit for burning. The several beds vary among themselves, and in different places, from a few inches to ten or more feet in thickness. The brownness of the turf, and the blackness of the peat, are due, we may note, to the changes which the woody matters of trees and herbage have undergone towards the stage of bituminisation, or, as the chemist would say, production of hydro-carbons.

The whole lies on an impervious layer of either shell-marl or clay; sometimes with iron oxide (bog-iron-ore or limonite) in large quantities. These deposits, from water first occupying the hollow area, filled up the pores and crevices of the bed-rock, whatever that may be, and thus "puddled" the bottom, making it water-tight.

To revert to the peat—the nature and thickness of the several layers above described, and the quality of the peat, vary according to the differences in climate and drainage of the places where the bogs have been formed, the various plants natural to the different localities, and the amount and kind of alluvial matters deposited among the aquatic plants, whether dead or alive.

The surface of a bog may be green with living moss, sedge, reeds, grasses, horse-tails, and other plants; it may have the blackness of the decayed vegetable mass beneath; it may be brown where turfy and dried (sometimes grey and tow-like when composed of dry, dead bog-moss), or various patches of green, black, and brown may form the surface.

The black uncovered mud is impassable over wide areas in many peat-swamps. Elsewhere a thin tough crust of fibrous roots and creeping stems of plants—either living, as in the bright green Irish "scraws," or dead, but not yet rotten, as in brown turf—covers the soft black mud, and just bears a swift runner over the quaking bog.

Tufted lumps of vegetation, in many parts, give a foothold to the bog-trotter, while more continuous growths of matted plants afford tortuous paths to the half-wild pony of the turf-cutter, as formerly to the reckless moss-trooper.

Elsewhere the bogs present a broad, brown level of thick, tough turf, which can be walked on, and shot over with dog and gun, in search of snipe and other birds frequenting the moister portions, ponds, and watercourses. Sometimes the "turf" is eight or ten feet thick, but often it thins out to a few inches, and then the venturesome sportsman sinks suddenly to his armpits.

An Alpine bog has the following history:—A mountain lake is formed when the flow of water gathered from mist, rain, and snow, is gradually intercepted by the hardy moss and stunted herbage, or more suddenly checked high up in a valley by gravel heaped by storm-waters in the gorge. Sometimes a lake is formed by the moraine of a spent glacier, acting as a dam. When the water of this upland lake has reached its limit of detention, it is gradually encroached upon by the water sword-flag (lobelia dortmanna), some floating riband-worts (sparganium natans), and straggling dwarfs of lake-rush (scirpus lacustris), all tending to displace the water until in time a bog supplants the lake. In the lowlands, with warmer valleys, the marshy lakes have a far greater variety of aquatic plants. Thus on the borders of our streams or shallow lakes (and even in the side-diggings of railway and such-like ponds) we find among the rank vegetation, adding largely by rotted leaves, stems, and roots to the black mud of the encroaching margins, the following plants:—Bur-reed (sparganium), reed-mace (typha), bog-rush (schœnus), rush (scirpus), sedge (cyperus and trasus), club-rush (elæocharis), grass-rush (carex), beak-rush (rhynchospora), reed (arundo), water meadow-grass (poa), water sweet-grass (catabrosia), reed-grass (calamagrostis), sweet-flag (acorus), toad-grass (juncus), yellow flag or "seggs" (iris), arrow-head (sagittaria), water-plantain (alisma), water-gladiole (butumus), peachwort (persicaria), water-violet or bog-featherfoil (hottonia), buck-bean (menyanthes), forget-me-not (myosotis), water sword-flag (lobelia), water-parsnip (sium), cowbane (cicuta), water-dropwort (œnanthe), water-hemlock (phellandrium), water-cress (nasturtium), crowfoot and marsh-marigold (ranunculus). Of the ferns that grow on water-margins, blechnum and osmunda, hard and royal ferns, are with us the most notable; and one of the thread-mosses (bryum) flourishes there also. Important adjuncts to these, freely invading the water in some places, are the creeping club-moss (lycopodium), and the bog-moss (sphagnum); whilst the needly hairy-mouth moss (trichostomum), the river bristle-moss (orthotrichum), and the water-moss (fontinalis), live in the water itself. Other plants, bending to the surface of the water, stretch off from land, such as some kinds of riband-wort (patanarium) and smooth-rush (isolepis), the flute-grass (glyceria), floating-rush (juncus), and the floating feather-moss (hypnum).

In the water flourish the pepper-grass (pilularia), horse-tail (equisetum), stone-wort (chara and nitella), pond-weed (zannichellia), river-weed (potamogeton), frogbit (hydrocharis), vallisneria in warm climates, pontederia and anacharis in America, water-soldier (statiotes), horn-wort (ceratophyllum), water-milfoil (myriophyllum), yellow and white water-lilies (nuphar and nymphæa), water-crowfoot (batrachium), and duck-weed (lemna).

These accumulate vegetable matter in a rotting mass, and form "submerged" peat, or that at the bottom of the water.

Of the plants already mentioned, some, such as the river-weed, frogbit, water-crowfoot, and duck-weed, float on the surface, and freely aid the marginal water-weeds in forming turfy rafts, floating, perhaps quite free, on some lakes, but rarely safe for human footstep. Thickened and covered by further growths, and at length over-weighted, or enveloped by flood-mud, they sink to the bottom, and help to make the "submerged" peat.

The minute but innumerable plants of simple structure, which live everywhere in both running and standing waters, add considerably to the peat mass. Besides the microscopic desmidiaceæ, there are many families of the confervoideæ, seen in floating, flocculent, greenish clouds of delicate silky filaments, outspread or interwoven, until they have passed their season, and sunk among the ruins of the larger water-plants.

The allied and associated minute diatomaceæ, with their microscopic shields, valves, frustules, or testules of pure silica, of exquisite form and symmetry, accumulate layers on the mud, or adhere to stems and leaves, or live amongst the confervoid filaments. In such waters as are favourable to them, the diatoms so abound that their imperishable frustules form a white meal-like deposit known as tripoli, polishing slate (polier-schiefer), mountain-meal (berg-mehl), flint-froth (kieselguhr), "Lord Roden's polishing-powder," &c., and formerly "infusorial earth," until it was discovered that diatomaceæ are really plants and not infusoria.

The peaty mass accumulated by these aquatic plants, and just rising above the inundation-level, becomes an "emerged" peat-moss, and gets its own particular set of plants as soon as the surface is free enough from superfluous water for those that require only a wet soil for their roots (so, also, in the early stage of a bog on a heath or hill-side, before it stops water enough for the purely aquatic plants). On these bogs, and adding to their turfy surface in many places, flourish the mud and marsh varieties of horsetail (equisetum), marsh bent-grass (vilfa), marsh silk-grass (apera), pipewort (eriocaulon), rush (juncus), bastard asphodel (abama), Scotch asphodel (tofieldia), marsh-rush (chætospora), bog-rush (schœnus), rush (scirpus), hare's-tail (trichophorum), cotton-grass (eriophorum), scheuchzeria, marsh-lousewort (pedicularia), and the insect-catching sundew (drosera). Several mosses, as fork-moss (dicranum), feather-moss (hypnum), hair-moss (polytrichum), and jungermannia, also affect these moist surfaces, and add to their sponginess. Still more effective are other feather-mosses with the bog-mosses (sphagnum), gland-moss (splachnum), grey marsh-moss (bartramia), and some thread-mosses (bryum).

The marsh-cistus (andromeda), cranberry or marsh-wort (oxycoccus), bog-myrtle (myrica), and the grey heath (erica cinerea) soon succeed; and the ground gets firmer and higher with the increase of fibrous peat or turf. Then willows (salix), with the birch (betula), alder (alnus), buckthorn (rhamnus), and occasional pines (pinus sylvestris), are the first to commence a forest-growth on what was not long ago a bog or a lake. The larger trees, however, swamped by floods, or by their own weight, and often easily blown down, are soon buried in the mossy soil, and add much to the peaty mass below.

The different kinds of peat have been variously classified, according to their composition, place of growth, and order of growth. There is (1) the *submerged* or under-water peat on the floor of the lake or pond; and (2) the *emerged* peat rising above the water-line. There are (1) dead and dying plants and fallen timber changing into peat, (2) real peat either fibrous or homogeneous; and either pure, as on mountains, or impure with mud or sand, as in many low plains, and then sometimes only half-peats. Some observers note the following kinds of peat: (1) Moss-turf, of sphagnum chiefly; (2) Grass-turf or meadow-turf, with rush and sedge (cyperaceæ); (3) Heath-turf or highmoor-turf, characterised by heath and heather; (4) Leaf-turf or forest-turf, made of fir-needles, and other leaves of trees; (5) Marine peat of seaweeds (algæ). Another grouping is—mountain-peat, marsh-peat, lake-peat, forest-peat (not quite the same as the forest-turf above mentioned), and marine peat.

For our present intention it will be convenient to classify these bogs or mosses, occurring under so many different conditions, and with special characters in different kinds of localities, as follows:—

I. Peat-bogs and turf-moors on such plateaux as flat mountain-tops and wide hill-moors. II. Peat-bogs of valleys: (1) At the heads of the valleys; (2) at the salient angles within river-curves; (3) in deserted bends of rivers; (4) in plains and lakes of expanded valleys; (5) river-deltas; (6) maritime peat-marshes, where certain valleys and plains (which are but broad valleys) open to the sea.

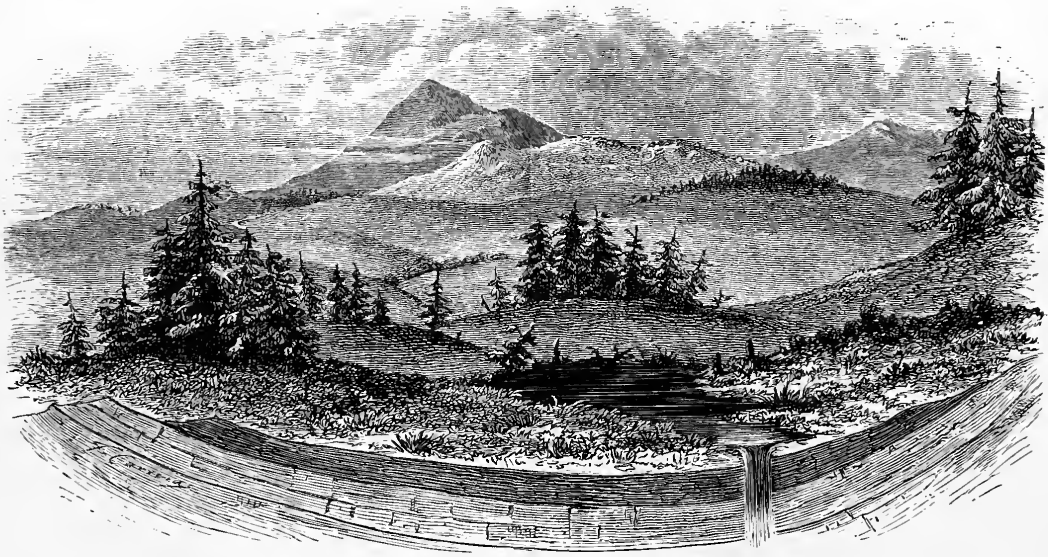


Fig. 1.—Peat-bog of Mountain Side. (*From a Sketch by C. Cooper King.*)

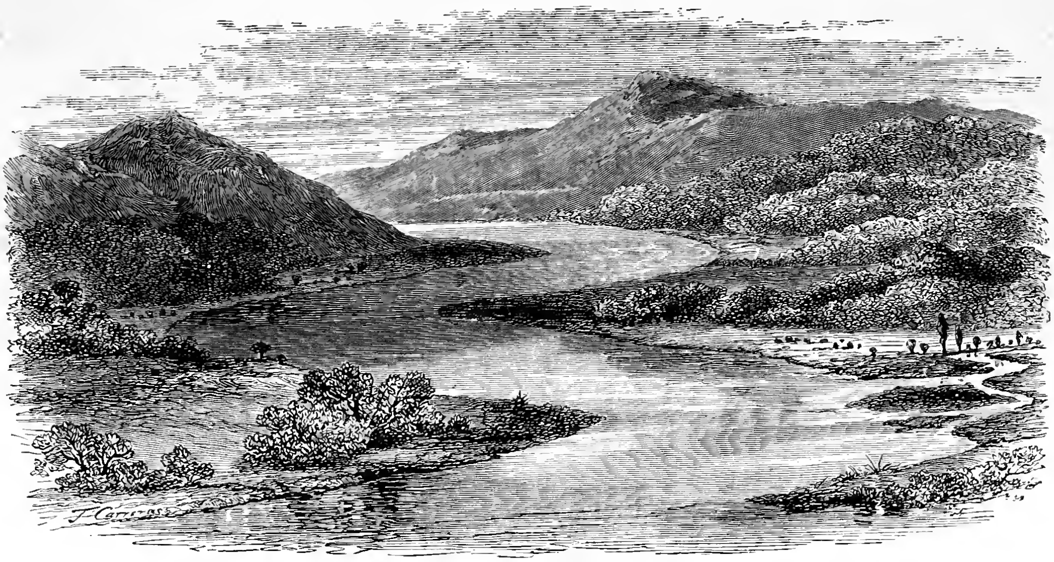


Fig. 2.—Peat of River Bends and Delta. (*From a Sketch by C. Cooper King.*)

We must remember, however, that, on both plateaux and plains, every gradation from puddles and ponds to lakes, and from marshes and fens to bogs, is found wherever the ground, being flat and impervious, can hold water on its surface.

I. Turf-moors and heath-turf.—In mountainous regions and other high grounds with broad flats, whether floored with rock, or consisting of an expanse of sand and gravel more or less cemented with iron-oxide or other materials, there are wide hollows retaining the rain-water; and the persistent moisture favours the growth of water-loving plants.

from the lowly hydrophytes, liverworts (hepaticæ), and mosses, to the more highly organised rush, sedge, grass, heath, &c. The fibrous peat or turf thus formed is common on high "heaths" and "moors;" and a large portion of mountainous countries, like

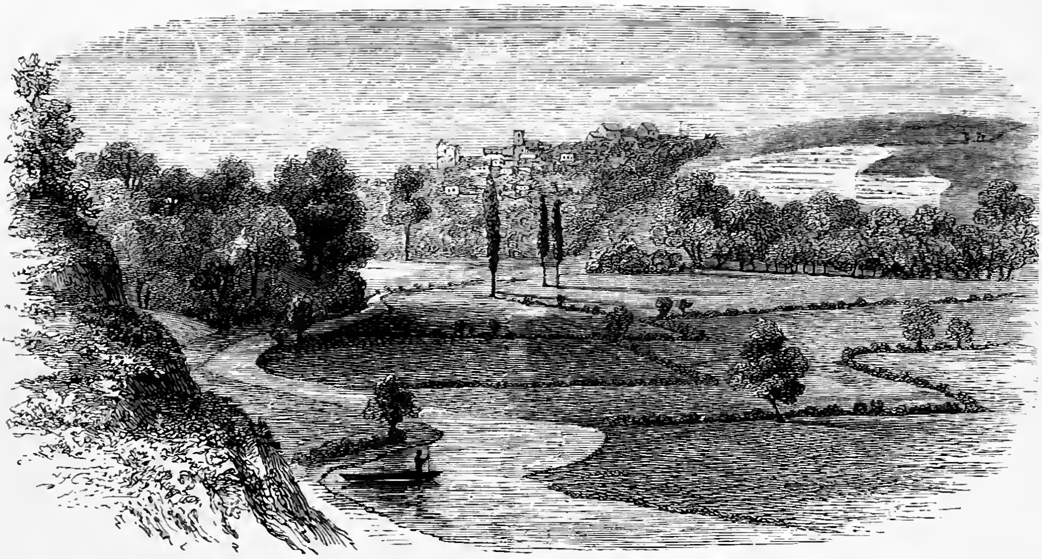


Fig. 3.—PEAT OF SILTED VALLEY. (*From a Sketch by C. Cooper King.*)

Scotland, for instance, is covered with such turf, which passes into true peat in the deeper hollows of the surface.

Some broad level highlands are always wet with pools and shallow lakes, the hollows having no free drainage; and thus moss-bogs are formed, often of wide extent, as on the broad limestone plains in Ireland, above and at the heads of the valley-drainage.

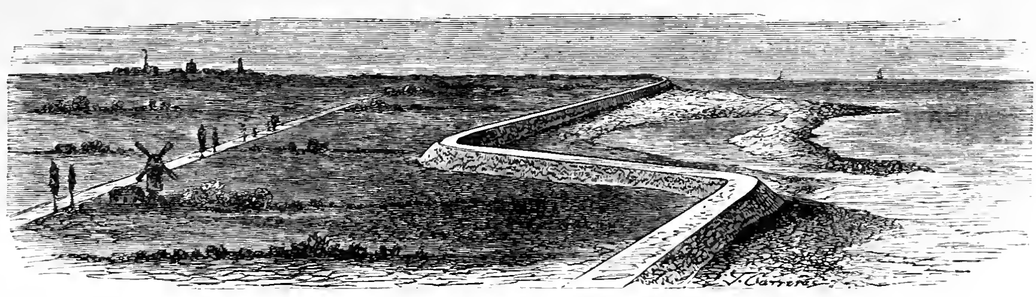


Fig. 4.—MARITIME MARSH; FENLAND. (*From a Sketch by C. Cooper King.*)

The Bog of Allen, occupying 230,500 acres, 250 feet above the sea, in King's County and Co. Kildare, partakes of this character. This morass rests on marl, clay, and limestone gravel, and is divided into several separate bogs by ridges of limestone, forming dry land. Its peat has an average depth of twenty-five feet.

II. Among the mountains of the British Isles, of Scandinavia, of Germany, and Switzerland, bog-moss and its associates have filled many hollows and valleys (see above, page 342) with decaying stems and roots below, and a green deceptive sward-like surface above the water-line (Fig. 1). The overflow of these wet spongy accumulations supplies the brown streamlets of the mountain-side. The growing sphagnum will long detain and hold up a vast quantity of water above a horizontal line, by capillary attraction; but ultimately, the limit of its imprisonment being attained, the liquid black mud of the bog bursts its bonds and inundates the lower grounds with wide-spread fetid desolation. Sometimes the swollen bog is naturally or artificially drained, and a great central depression offers

cultivatable land, requiring, however, much care and manure to make it fertile. Chat Moss, on a northern tributary of the Mersey, in Lancashire, is a large morass which has been traversed by a canal, crossed by the Manchester and Liverpool Railway, and drained and cultivated successfully, at great expense.

Rivers follow greater or less curves in their course, according to their slope, the volume and rapidity of the stream, and the various obstructions met with. In making these curves the river eats away the steep and hollow cliffs against which it rushes, and leaves a projecting angle on the opposite bank, where the current is weakened and even turned back a little. Here, then, mud and sand are deposited, and form a tongue of marsh-land (Fig. 2). Marsh-plants find a home here; and they aid and even surpass the earthy materials in displacing the shallow water. Thus equisetum, iris, arundo, carices, and others, flourish and fade, with the regular alternation of the seasons, and constitute a *submerged* peat. In time their black muddy residue so nearly touches the water-line that sphagnum and its allies succeed, and raise the decaying vegetable mass still higher; and thus an *emerged* peat-bog presents its deceitful surface of verdure.

When the "bends" of a serpentine river become excessive, almost circular, the neck of land between the two limbs of the curve, at its beginning and end, is cut through; and the curved portion, bend, or arc, deserted by the main stream, is gradually silted up. The flood-mud of wet seasons, and ultimately aquatic plants, raise its bed; whilst from the banks grasses, sedges, and the usual marsh plants encroach steadily on its muddy shallows, until sphagnum, horse-tail, or other peat-plants, cover the black bog, wholly or in part, with a soft green carpet. The cane-brakes and cedar-swamps of the Mississippi are examples of these peat-bogs.

Enormous gorges, eaten out by water and ice, along cracks in the earth's rocky crust, far back in geologic times, and then choked up with the stones and mud of glacial moraines and torrential wreck of mountains, until broad plains of gravel and sand were formed, have received their last deposits of alluvial loams by the quiet action of existing rivers. Hence sometimes grassy prairies or wide forests; but often broad swampy flats, varied with desolate peat-bogs, rank cane-brakes, or sedgy moors, all characterised by the dead level of the former water-line (Fig. 3). According to the various conditions of the meandering rivers, fresh-fed lakes, and stagnant marshes in the broad valley, vegetable matter, derived from the plants peculiar to the situation, will accumulate in hollow places and form peat, rising with its turfy texture somewhat above the water-level. Freshets of rain-water, or snow-water, casually spreading sand and gravel over the boggy margins and the back-waters ("jeels," "slakes," &c.) of the rivers, raise barren wastes for a time, until these weigh down the mud below, and become coated with a new peat-moss. So also will a wide extent of bog have deeper water on it for a time, and, ceasing to grow its usual water-weeds, become the floor of a clear lake, inhabited by fresh-water snails and mussels (limnæa, paludina, cyclas, anodon, &c.), and lime-bearing water-plants (chara), until successive generations have left thick layers of white marl or "malm." Then, silted up to a fit shallowness again, the lake is choked with aquatic vegetation, excepting the current-course of its feeding stream, and renews the aspect of a peat-bog. A morass as long as England extends from the fifty-second parallel of latitude along the course of the Prepit, an affluent of the Dnieper.

Sometimes flooded rivers inundate neighbouring forests, and leave them swamped, to die and rot, with the spongy bog-moss creeping up among their prostrate trunks and branches, until it raises its water-laden mass of rotting fibres and false green mask above the ancient forest-land.

The great antiquity of some peat-mosses is shown by the succession of dead forests one over the other, and separated by thick peat-beds, indicating successive sinkings of the over-loaded surface, and its renewal by the growth of peat. Great periods of time are bespoken by the successive forest-growths, each consisting of different species of trees, and have been required also for the intermediate slow growth of peat.

In Denmark, where peat-mosses abound, there are some of great interest, though of limited extent, which have been formed in cauldron-like cavities in the boulder-clay. These great "pot-holes" are of obscure origin: they may have originated by great masses of ice, or of frozen mud, having been deposited, and subsequently melted, letting down the overlying beds; or they may be due to the boulder-clay having been laid down over fissures and pot-holes in the rock on which old glaciers had worked, and so sunk down. At all events they have been the receptacles of lakes, with bed-clays retaining remains of arctic birch and willow, and with shell-marls, on which were formed various peat-beds in succession. On the margins of these, trees of successive forests grew and fell in. The early pine

forests, with the stone weapons of the aborigines; and the succeeding oaks, with bronze weapons of another race of men; and the beeches at last, with the iron implements of historic man: these are clearly seen there, one after another.

Looking at the result of the decay of plants on a large scale, where the conditions have not allowed of the permanent formation of wet marshes, we notice the enormous extent of the black earth (tchornos-jom or tchernay-zem) of Russia. This covers a vast region, over the valleys of the Don, Dnieper and Volga, of more than 197,500,000 acres, with a thickness of from three to fifteen feet, and sometimes (it is stated) to thirty and even sixty feet.

Where rivers enter the sea, and their checked current can no longer hold even mud in suspension, shoals, bars, sand-banks, and mud-banks accumulate to form "deltas," with lagoons of imprisoned sea-water, with isolated "bends" and deserted "reaches" of devious watercourses, and lakes in hollows ot the soil. These get choked with water-plants and silt, either persistently or by interrupted stages. Hence arise morasses and peat-bogs, often of great extent, and frequently containing layers of sea-sand, and other evidences of past invasions of the sea. The salt-marshes get their peaty soil from the sea tassel-grass (ruppia), sea river-weed (potamogeton), pickle-rush (cladium), sea-rush (scirpus and juncus), smooth-rush (isolepis), sea meadow-grass (poa), sea-grass (spartina), sea-bent (vilfa), shore-beards (polypogon), sea arrow-grass (triglochin), besides desmids, confervæ, and other minute plants of simple structure. Where the sea itself has heaped vegetable matter, the grass-wrack (zostera), oar-weed (laminaria), sea-wrack (fucus), and other sea-weeds, form more or less distinguishable heaps and beds.

The slow infilling of a great river-gorge, both up the country, and especially at the coast, where the sea helps it to form its delta, is thus accompanied with the formation of peat; and wherever the valleys are relatively broad, they exhibit wide marshes when subject to overflow of river and sea, and broad forest-lands or grassy flats when free from inundation. Such alternations of river-silt, sea-mud, fallen timber (local in origin or drifted), lake-shells, sea-shells, shingle, peat, clay, and marl, in many different associations, are visible in numerous cuttings in the fen-lands of England and Holland, and in many other sections of old marsh-lands bordering the sea, and of some farther inland, in the British Isles and elsewhere (Fig. 4). Interesting evidences of geological changes, due to varying conditions of land and sea, have been recorded (for instance) as shown by such sections, in Shropshire (J. Trimmer), in Somerset and elsewhere (Godwin-Austen), Scotland (Macculloch, Duke of Argyll, James Geikie), Swansea (M. Moggridge), fen-lands (Skertchley and others), Denmark (Forchhammer, Steenstrup), &c. As an instance of such maritime fen-lands, we may refer to the "Bedford Level," including the Isle of Ely in Cambridgeshire, Peterborough fen, Northamptonshire, the Parts of Holland in Lincolnshire, about 60,000 acres in Huntingdonshire, 63,000 in Norfolk, and 30,000 in Suffolk, comprising the greater portion of the "Fens," a marshy flat, intersected by the Nene, Cam, Ouse, and Welland rivers. The Romans formed an immense embankment here, which excluded the tide, and rendered the district for a time very fertile, until the sluices became choked, and the level was gradually converted into one vast morass, increased by inundations of the sea in the thirteenth century. Various attempts were made to drain it in the reigns of Henry VI. and Charles I., and it was fully reclaimed by the Earl of Bedford in the seventeenth century. The sea again burst the barriers in 1863. This tract produces fine crops of grain, flax, and cole-seed, also hemp, mangel, and potatoes. These flat fen-lands are crossed by banks, ditches, and canals in many directions, all having reference to the lines of natural or artificial drainage. The country is thinly wooded; and here and there are farm-steads and villages on slight eminences. Seaport towns are traversed by the larger rivers near their mouth.

Extensive regions, including the mouths of the great rivers, in northern and western Europe, having been deserted by the sea, are passing through the successive stages of saltmarsh and fenland; and wide tracts have become cultivated plains. Such are the low grounds of the ancient gulf of Poitou, the filled-up estuary of Flanders, the largest part of Holland, and of German "Friesland."

The Tûndras of Northern Russia and Siberia, now permanently frozen below, and covered with snow nine or ten months of the year, are also characteristic maritime swamps, involving the broad, low deltas of the great rivers that enter the Arctic Ocean. These extensive and melancholy flats are varied with lakes of salt and fresh water, and are green with coarse grass, rushes, and sedge, and with plots of bog-moss, during their short summer of nine or ten weeks. Whatever else the unsearch-

able tûndras may contain, the ancient mammoth and rhinoceros, still preserved entire in their frozen muds, tell of long past changes in north Asia. But in Europe and the British Isles, where nation has pressed upon nation in forced emigrations, the peat-bogs teem at places with recognisable relics of the past.

Weapons and tools of stone, bronze, and iron, besides the bones, garments, and ornaments of man, also his canoes, his crannoges or artificial island forts, and his pile-structures, once supporting huts and even villages in marshes and lakes, with the associated rude or finished implements, and other belongings of his domestic life, are all found in peat-bogs, and can be referred to many successive ages, and to different peoples. Thus, when fully studied, a peat-bog often enables us to obtain an insight, not only into many geological changes in far-back time, but also into the history of races of men who have left no written records, no buildings of brick or stone, to bear witness of their life, yet nevertheless played an active part in founding the civilisation in the midst of which we now live.

A PIECE OF ICELAND SPAR.

By George W. von Tunzelmann, B.Sc.

ICELAND SPAR (Fig. 1), or Calc-spar, consists of carbonate of lime crystallised in transparent rhombohedra, and it derives its first name, the one

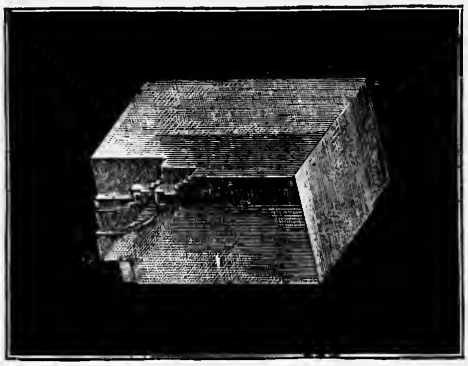


Fig. 1.—A Crystal of the Spar.

by which it is most generally known, from the fact of its occurring in large quantities in Iceland.

If a piece of the spar be laid upon a wafer, then, on looking through the crystal we shall see two images of the wafer, which will vary in distance and relative position according to the direction in which we look at it through the spar. These two images are always fainter than the original, as may be seen very strikingly by looking at the object in such a direction that the two images may partially overlap, when it will immediately be noticed that the overlapping part is considerably darker than the remainder. Instead of using a wafer, we may, if we please, lay the crystal of spar upon the page of a book, when all the letters seen through it will appear double (Fig. 2).

Fig. 2.—Double Refraction of Iceland Spar.

This property of Iceland spar was discovered in 1670, by Erasmus Bartholin, and very soon attracted the attention of Huyghens, the great originator of the wave theory of light. Huyghens sought to account for the phenomenon by means of the new theory, and the laws to which he was thus led were experimentally verified by Wollaston and Malus during the early part of the present century. In order to obtain a clear idea of the phenomenon of *double refraction* in Iceland spar, we must first understand the form of the crystal.

It is seen at once from our illustrations (Figs. 1, 2) that the crystal is bounded by six parallelograms, and that it has eight corners, each of which is the meeting point of three of the sides, and the vertex of three plane angles. It will be noticed that since the sides are in the form of parallelograms, the lengths of all the edges will be determined if we

know the lengths of the three edges which meet at any vertex. The lengths of these three edges may have any ratios, but the angles of the crystal are the same in all specimens, and out of the eight vertices there are two, opposite to each other, which are each the common vertices of three equal obtuse angles. If through one of these two vertices we draw a straight line, equally inclined to the three edges meeting at that vertex, any straight line parallel to this is called an axis of the crystal; so that the axis is not a definite straight line, but a definite direction. Now, let A B C D (Fig. 3) represent a section of a crystal of Iceland spar parallel to one of the faces, and let I K be a ray of light incident upon the upper face of the crystal at the point K; then, instead of simply being bent or refracted into a fresh path K O, the incident ray I K gives rise to two refracted rays K O and K E, of which K O is known as the ordinary, and K E as the extraordinary ray.

We now see how it was that, on looking through a crystal of the spar at an object beneath, we saw the object double, for the rays coming from it will be broken up into two pencils taking different

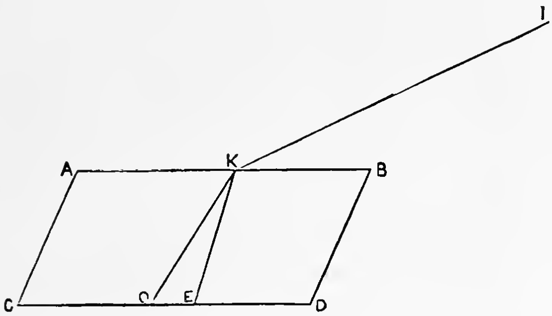


Fig. 3.—Showing Double Refraction of Ray Incident upon Crystal of Iceland Spar.

paths through the crystal, and therefore the eye will receive two distinct images.

If we lay a crystal of Iceland spar upon a wafer or dot upon a piece of paper, and then make the crystal rotate, always keeping the same point of it in contact with the wafer or dot, we shall notice that one of the images will remain fixed, while the other will rotate round it. The former is called the ordinary image, as it is formed by the ordinary rays; the latter is formed by the extraordinary rays, and is therefore called the extraordinary image. In order to understand the difference between the ordinary and extraordinary rays, we must revert for a moment to the consideration of the ordinary refraction of a ray of light passing from one uncrystallised transparent medium into another, as from air into glass, or from air into water, as in the experiments described at p. 192, Vol. I.

Let A B (Fig. 4) represent the surface of separation of two such media, such as air and water. Let I O be a ray incident upon the surface of the water at the point O, and let O R be the refracted ray in

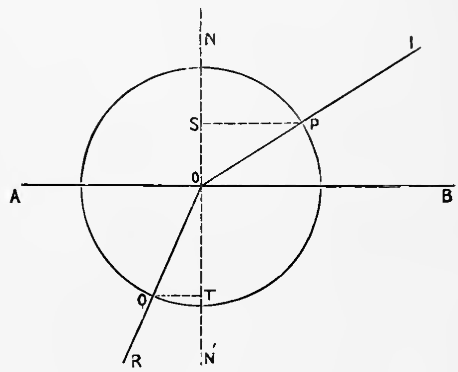


Fig. 4.—Illustrating Angles of Incidence and of Refraction.

the water to which it gives rise. Through O draw N N′, the normal or perpendicular to the surface of separation, and from the centre O describe a circle with any convenient radius, and from the points P and Q, where the two rays cut the circle, let fall perpendiculars P S and Q T to the normal N N′; then it is found that for the same two media the ratio of the two perpendiculars, S P and Q T, is always the same.

Now, $\frac{SP}{OP}$ is called the sine of the angle of incidence N O I, and $\frac{TQ}{OQ}$ is the sine of the angle of refraction, N′ O R. Therefore, since O P and O Q are equal, the law may be stated thus:—For the same two media the sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction, which is generally quoted as the law of sines.

This ratio is called the relative index of refraction between the two media, and if the ray is passing from a vacuum into any medium, the ratio, which is in that case always greater than unity, is called the absolute index of refraction of the medium.

Now, in the case of the two refracted rays which arise from the incidence of a single ray upon a crystal of Iceland spar, the ordinary rays follow the law of sines, but the extraordinary rays only follow this law in the special case when the plane of incidence (*i.e.*, that plane which passes through the incident ray and is perpendicular to the surface upon which it is incident) is perpendicular to the axis of the crystal, and then their index of refraction,

called the extraordinary index, is different from the ordinary index, or index of refraction of the ordinary rays. If the rays of light are incident in the direction of the axis of the crystal, this splitting of it up into two rays does not take place, so that if we cut a slice of the crystal perpendicularly to the axis, and lay it upon a small object, then, upon looking vertically downwards at the object, we only see one image of it, but two images are immediately seen if we look at it obliquely through the crystal. The distance between the two images increases with the obliquity of the incident rays until they are incident at right angles to the axis, when the separation between the two images attains its greatest value.

What Huyghens succeeded in doing was to find a geometrical construction, which for any direction of the incident rays would determine the direction of the two refracted rays, but he made no attempt to explain the origin of the two systems arising in a crystal of Iceland spar.

In 1739 M. Dufay showed that double refraction never took place in non-crystallised substances, nor in crystals of the cubic system, which are symmetrical about three equal axes at right angles, and therefore are symmetrical about a point. M. Dufay's observations were confirmed by Haüy, who showed that all crystals which did not belong to the cubical system, and were therefore not symmetrical about a point, possessed the property of doubly refracting a ray of light.

Besides the Cubic system of crystals, there are five others. The Right Square prismatic, or pyramidal system, which has three axes at right angles, but only two of them are equal. The Rhombohedral or Hexagonal system has four axes; three of them are of equal length, lie in the same plane, and cross each other at angles of 60°, while the fourth is perpendicular to them, and of varying length. The Right Rectangular Prismatic, or Prismatic system, has three axes, all at right angles to each other, but all of different lengths. The Oblique system has three axes, which may be of any lengths; two of them cross each other obliquely, while the third is perpendicular to both of them. Finally, there is the Doubly Oblique system, with three axes, which may all differ in length, and all crossing one another obliquely.

In 1818, Sir David Brewster discovered that crystals of the right square prismatic and the hexagonal systems, which are symmetrical about a straight line, are characterised by the existence of one optic axis or axis of single refraction, while crystals of the three remaining systems have two optic axes, or directions in which a ray of light may pass through them without being split into two.

The first class of doubly refracting crystals are called uniaxal crystals. In these the optical properties are the same for all directions equally inclined to the optic axis, but vary with the inclination. The second class are known as biaxal crystals.

The undulatory or wave theory of light does explain and account for the phenomena of double refraction, but in order to do so it has to seek aid from the theory of elasticity. A ray of light consists—according to the wave theory, now universally accepted—of vibrations in all possible directions, perpendicular to the direction of transmission of the ray. The medium by which these rays are transmitted is called luminiferous ether, and we must assume that it fills all known space, and interpenetrates all substances. Some proofs of the existence of such a medium, in addition to the explanation which it gives of the phenomena of light will be found in Vol. II., p. 6. Knowing as we do the enormous rapidity of light-vibrations, we learn from the ascertained principles of the theory of elasticity, that as regards wave transmission the luminiferous ether behaves as an extremely elastic solid, though at the same time we know that it allows the heavenly bodies to pass through it without perceptibly retarding their motion.

Now in order to submit the question to mathematical analysis, we have to make some assumptions about the constitution of the ether within the crystal, but in order that the theory to which we may thus be led may be anything more than merely a specimen of mathematical ingenuity, we must carefully see that our assumptions are permissible. We shall first assume that the ether within the crystal is so constituted that there are three directions at right angles to each other, in which, if a particle be disturbed, the forces acting on it will tend to move it back in the same line in which it was displaced, always supposing the displacement to be extremely small. M. Fresnel, starting with the most general supposition possible with regard to the forces called into action by a small displacement, has shown that this will be the case, so that our first assumption is justified. The meaning of this assumption will be more easily grasped by means of an experiment due to Professor Blackburn, of Glasgow, and which the reader will have no difficulty in performing. A and B (Fig. 5) are two points in the same horizontal line, to which

are attached two cords, A C and B C, which are of equal length. To C another cord is attached, carrying a weight D to act as a pendulum-bob. There will then be three displacements, which may be given to D, such that D will move back in the line of displacement. First, D may be drawn aside in a plane perpendicular to the paper, keeping the strings stretched, when it will vibrate about the axis A B, and the length of the pendulum will be D E. Secondly, D may be displaced in the plane of the paper; keeping the string C D stretched, D will then vibrate about an axis through C, perpendicular to the plane of the paper, and the length of the pendulum will be C D. Lastly, D may be displaced perpendicularly upwards, when it will simply fall back to its first position. The first two displacements were along arcs of circles, but at the commencement of the displacement, or for a very small displacement, the direction of motion would be along the tangent to the circular path at the point D; in other words, the three small displacements are, along D E and along two straight lines, through D and perpendicular to D E, in and perpendicular respectively to the plane of the paper. For any other displacement, D will not immediately return through the point of rest, but will first execute curves round it.

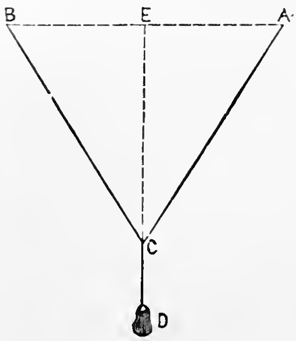


Fig. 5.—Illustrating Action of Force in Lines of Displacement.

Returning now to the doubly refracting crystal, the second assumption which we shall make is that these three directions are determined by the form of the crystal, an assumption which is justified by the observation which we have already considered, of the connection between the optical properties of a crystal and the crystalline system to which it belongs. These three directions form the axes of elasticity, and we learn from the mathematical theory of elasticity that two of these directions are the directions of greatest and of least elasticity respectively. Now, as we have pointed out, the optical properties of uniaxal crystals are the same for all directions equally inclined to the axis, but vary with a change in the inclination. That is to say, that for all directions equally inclined to the axis the elasticity will be the same, but will be different in directions unequally inclined to the axis.

Now, when a beam of common light impinges upon such a crystal, the effect produced by this variation in the elasticity for different directions is that the series of vibrations in all possible directions perpendicular to the path of the ray resolves itself into two, one parallel to a given plane passing through the line of transmission of the ray, and the other perpendicular to that plane. These two series of vibrations are said to be plane-polarised, and we shall see how experiment leads us up to this same conclusion with regard to the difference between common and plane-polarised light—viz., that in common light the vibrations take place in all directions perpendicular to the path of the ray, while in polarised light, while still perpendicular to the path of the ray, they are all executed in one plane passing through the line of the ray; in other words, the vibrations of a ray of plane-polarised light are all parallel. But while experiment leads us to this same conclusion, it merely tells us the fact without accounting for it, while the theory of elasticity explains to us why it is that this resolution takes place. The discussion of this would lead us into very difficult mathematical analysis, but taking this step for granted we shall not find it hard to understand how it is that these two series of vibrations give rise to two separate rays.

First of all, we must note that the velocity with which a vibratory disturbance is transmitted through any medium, is greater as the elasticity of the medium is greater. Now, when a wave is sent through a medium, each particle of the medium along the path of the wave is more or less displaced, and executes vibrations about its position of rest which are more rapid as the elasticity is greater. To illustrate this we may take two springs of the same dimensions, one considerably stronger than the other—that is to say, having a greater elasticity; if we now attach equal weights to the two springs and then pull them down through the same distance and let them go, we shall see that the weight attached to the stronger spring will vibrate more rapidly than that attached to the weaker one.

Now, the directions of the two series of vibrations into which the ray of common light is broken up as it passes into the crystal, are those two directions perpendicular to the path of the ray along which the elasticity is respectively greatest and least. The two series will therefore travel with different velocities, but we have yet to explain why they should travel in different directions. To do this we must inquire into the explanation which the wave theory of light gives us of refraction. We

will consider the case of refraction between two optically isotropic media, a medium being called optically isotropic when a wave is propagated with the same velocity in all directions. It is then clear that when a ray impinges at any point of the surface of such a medium, the front of the resulting wave will be spherical, since it is travelling with equal velocity in all directions. A very good illustration of this may be obtained by throwing a stone into a pond, when we shall at once see a number of concentric circular waves proceeding outwards from the stone as centre, these circles being simply the intersections of the successive positions of the wave-front with the surface of the water.

Now let A B (Fig. 6) represent a section of part of the separating surface between two isotropic media, such as air and water, or water and glass, and let B C be part of a wave-front in the first medium, both portions being small enough to be treated as plane. From B describe a sphere with a radius equal to the distance light would travel in

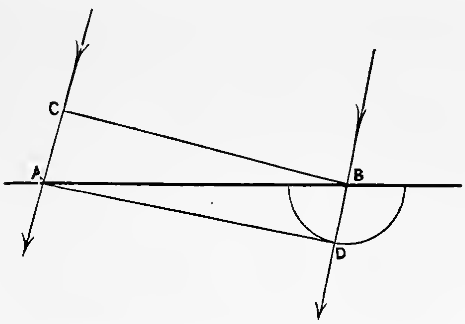


Fig 6.—Illustrating the Relation of Velocity to Refraction.

the second medium while it travels over the distance C A in the first medium.

Through A draw a tangent plane to the sphere, touching it at the point D. Then the tangent plane A D is the wave-front in the second medium. Now the point D is in the plane of incidence, which gives us the first law of refraction, that the plane of refraction is the same as the plane of incidence. Again, the angle C B A between the first wave-front and the surface of separation is equal to the angle between the direction of the ray and the normal to the surface, that is the angle of incidence.

Similarly, the angle B A D is equal to the angle of refraction.

But, as we have already seen, $\frac{CA}{AB}$ is the sine of the first angle, and the sine of the second is $\frac{BD}{AB}$. The index of refraction is therefore $\frac{CA}{BD}$, *i.e.*, the ratio of the velocity of light in the first medium to its velocity in the second.

The amount of refraction therefore depends upon the velocity with which the wave is transmitted. Now we have seen that the two series of vibrations in our crystal of Iceland spar were travelling with different velocities, and therefore the one will be more refracted than the other, which explains why it is that the ray bifurcates.

In Iceland spar the elasticity is least for vibrations perpendicular to the axis.

Now, let us remember that the axis is simply a direction, and take any plane oblique to the axis, then from any point in the plane we can draw one plane perpendicular to the axis, which will cut the given plane in a line perpendicular to the direction of the axis; if through the same point in the plane we draw a line at right angles to this it makes a smaller angle with the axis than any other line in the plane.* The former of these two lines is the direction of least elasticity and of vibration for the ordinary ray, and the latter is the direction of greatest elasticity and of vibration for the extraordinary ray.

The ordinary rays are transmitted with the same velocity in all directions, since the elasticity is the same in all directions perpendicular to the axis, and therefore, as we have seen, the wave-surfaces are spheres, and the rays will be refracted according to the law of sines. In the extraordinary rays the velocity of transmission varies with the inclination to the axis, and the wave-front will be an oblate spheroid (a figure of which the earth is an example), having its shorter or polar diameter equal to the diameter of the spherical wave-front of the ordinary rays, and in the same direction as the axis of the crystal. At the extremities of this diameter the sphere touches the spheroid, so that for this direction the ordinary and extraordinary rays coincide, as we already know to be the case experimentally.

Tourmaline is another doubly refracting uniaxal crystal, and it possesses the property of absorbing the ordinary much more rapidly than the extraordinary rays, so that a sufficiently thick slice, which is moderately transparent to the extraordinary, is almost completely opaque to the ordinary rays.

To illustrate this we may take two slices of tourmaline cut parallel to the axis, and turn one of

* The reader will find that the easiest way to get a clear conception of the relation between these lines and planes will be to take two pieces of cardboard to represent the planes and a knitting-needle to represent the direction of the axis.

them about upon the other through different angles—it will be found that the combination is most transparent when the two axes are parallel (a b), and most opaque when the two axes are at right angles (A B, Fig. 7).

We can now explain this in the light of our previous knowledge. As the rays of light were

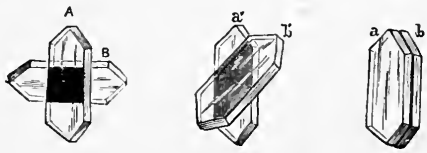


Fig. 7.—Tourmaline Plates.

passing through the first crystal, their vibrations were resolved into two series, one parallel and the other perpendicular to the axis; the former constituted the extraordinary rays, and the latter the ordinary, which, as we have remarked, are almost completely absorbed by tourmaline.

The extraordinary rays alone would therefore pass into the second crystal; and, if the axes were parallel, the vibrations constituting the extraordinary rays, being parallel to the axis of the first crystal, would likewise be parallel to the axis of the second, so that these rays would pass through both crystals with comparatively little absorption; if, however, the axes of the two crystals were at right angles, the vibrations which were parallel to the axis of the first would be perpendicular to the axis of the second, so that the extraordinary rays in the first crystal would give rise to ordinary rays in the second, and in passing through it these would be absorbed.

When all the vibrations constituting a beam of light are perpendicular to a particular plane, the light is said to be polarised in that plane. When a ray of light is merely resolved into two sets of vibrations at right angles to each other, we have no means of distinguishing such a ray from a ray of common light unless we can separate the two sets, when we get two plane-polarised rays, and we have ready to hand a method of distinguishing such a ray from a ray of common light in the slices of tourmaline cut as we have described; for if a ray of common light be allowed to fall on one such slice, it will appear equally transparent in all positions of the slice; but if the ray be plane-polarised, then we shall have two positions of the slice at right angles to each other, which give respectively the greatest transparency and the greatest opacity.

The defect of this method of obtaining plane-polarised light is that if the plates are thick enough to absorb completely the ordinary rays, a considerable part of the extraordinary rays are also absorbed, while if we decrease the thickness of the plates, the ordinary rays will not be completely absorbed, and the light will be only partially polarised. In order to avoid this defect we have recourse to other means of polarising a beam of common light, or of determining whether a beam of light from any source is polarised. One of the most efficient contrivances for this purpose is the Nicol's prism, so called from the name of its inventor (Fig. 8).

In Nicol's prism is concerned the phenomenon of total reflection by transparent media. This may easily be observed by holding a glass of water with a spoon in it above the level of the eye, when the under surface of the water will appear like a polished mirror, and the part of the spoon below the water will be seen reflected in it; but for the present we shall defer the mathematical explanation of this phenomenon as, perhaps, too intricate for a paper of this description.

To make a Nicol's prism we cut a rhomb of Iceland spar diagonally, and cement the two pieces together again with Canada balsam, whose refractive index is between the ordinary and extraordinary indices of the spar.

On entering the spar a ray of common light (S I) is broken up into an ordinary and an extraordinary ray; the former of these is totally reflected at the first surface of the balsam, and passes out at the side of the prism (o O), while the extraordinary ray is transmitted through the layer of balsam (a b c d) and emerges from the prism (e E) parallel to its original direction.

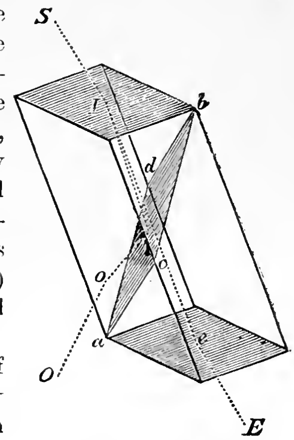


Fig. 8.—Nicol's Prism with Ray of Light passing through it.

Another method of polarising light is by means of reflection from non-metallic substances. For every reflecting substance there is a certain angle of incidence which gives the maximum amount of polarisation in the reflected rays, and this angle is called the polarising angle of that substance, and is such that the refracted and reflected rays are at right angles, and both these rays are found to be polarised, and their planes of polarisation are at right angles to each other.

Polarisation by reflection may be well shown by means of Malus' polariscope (Fig. 9). It consists of two reflectors—one (A) for polarising the light, and the other (B) for examining or analysing it, each reflector being composed of a pile of glass plates. The reflectors revolve upon horizontal axes, and the upper one also upon a vertical axis. The best effect is obtained by setting each of the mirrors at

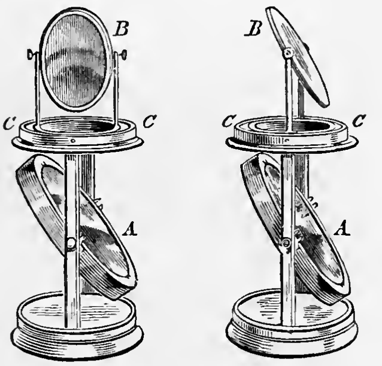


Fig. 9.—Malus' Polariscope.

an angle of about 33° to the vertical, and then allowing a beam of light to fall on the lower reflector in such a direction that it may be reflected vertically upwards. If we then look into the upper reflector, we find that as we rotate it about the vertical axis there are two positions differing by half a revolution, in which we see a black spot in the centre of the field, being those positions in which the upper reflector is incapable of transmitting the light reflected by the lower. The positions of maximum intensity are at right angles to these, being that in which the two reflectors are parallel, and the position differing from this by half a revolution. The instrument (Fig. 9) is provided with a perforated stage (C) to support the substance to be examined by polarised light. Instead of the two mirrors it is still better to use two Nicol's prisms, mounted so that they have a common longitudinal axis about which one of them can be rotated, and provided with means of fixing the substance to be examined between them.

If we examine in this manner a thin piece of selenite, a crystallised form of gypsum or plaster of Paris, we shall find that as we rotate the analyser—*i.e.*, the upper mirror or prism, as the case may be—the selenite will in some positions of the analyser appear highly coloured, the colour appearing most strongly when the analyser is in the position which gives either the maximum or minimum intensity of light, and the colour is changed into its complementary by turning the analyser through a quarter-revolution.

If the slice of selenite be turned round, changes in the colours will be observed, unless the analyser is in the position which gives either the maximum or the minimum intensity of light, in which case the colours will merely change in intensity and not in their tints. With thicker plates of selenite we get no colour, but if, when the analyser is in such a position that the light after passing through a thin slice of selenite is extinguished, we replace the thin slice by a thicker one, we can restore the light which was before extinguished.

To assist us in obtaining a clear idea of the reason why these gorgeous colours are to be seen in many objects when observed by polarised light, we will again call Professor Blackburn's pendulum to our assistance.

Referring to Fig. 5, let us imagine a plane through D and perpendicular to D E, and therefore to the plane of the paper. Then there are two straight lines in this plane, along which if D be displaced it will return along the line of displacement, and pass through its original position at each half-vibration—viz., the line in which the supposed plane cuts the plane of the paper, and the line through D perpendicular to this. If D be displaced along any other line in the plane, it will not immediately return to its original position, but will swing round it in a curve, which for small displacements is very nearly an ellipse or flattened circle. Let us now suppose that a beam of polarised white light falls perpendicularly upon a slice of selenite laid so that the direction either of greatest or least elasticity may lie in the plane of polarisation; then, since these two directions are at right angles, the one which does not lie in the plane of polarisation will be in the plane at right angles to it, in which are performed the vibrations of the polarised beam.

If we now turn the slice so that the direction of vibration no longer coincides with the direction either of greatest or least elasticity of the selenite, each particle of luminiferous ether when displaced will not vibrate backwards and forwards in a straight line, but will move in an extremely minute ellipse; for just as in Blackburn's pendulum, when the bob is displaced in other than the two cardinal directions, the restoring force called into play by the displacement is not in the direction of displacement, and therefore instead of sending the particle back through its mean position, it causes it to move round it in a curve which, as we have already stated, is an ellipse.

Now the difference between the velocity of propagation in the directions of greatest and least elasticity is greatest for the rays of shortest wavelength, or violet, and least for the red, so that the ellipses are different for the different colours.

The reader may very easily illustrate this by altering the ratio of the length E C to the length C D in Blackburn's pendulum (Fig. 5). Owing to this difference, the different colours will be unequally suppressed in any position of the analyser, which explains the production of colour. Now if we take any two positions of the analyser at right angles, we shall find that the colours are complementary, which we might have predicted, for the light suppressed in one position is the light which is not suppressed in the other, and neglecting the quantity absorbed in passing through the slice, the sum of these two components must be equivalent to the incident beam of white light —in other words, they must be complementary.

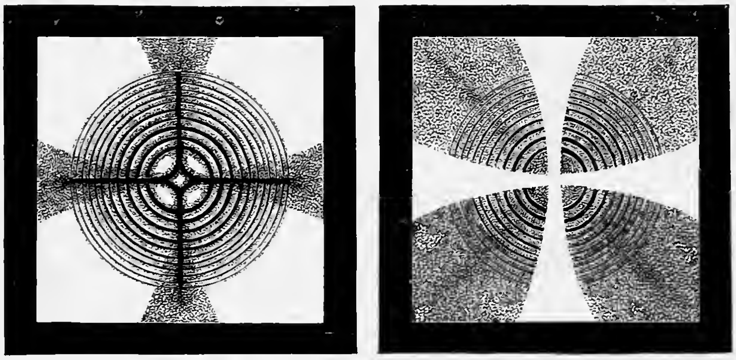


Fig. 10.—Rings and Crosses formed by Polarised Light passing through a Section of a uniaxal Crystal cut perpendicularly to the Axis.

We are justified here in neglecting the light absorbed, because the different colours are absorbed to very nearly the same extent, so that the colour is not sensibly changed by the absorption. If the plate of selenite be of a certain thickness the vibrational ellipse becomes a circle, and then there is no change in the intensity of the light as we rotate the analyser, so that in this it resembles ordinary polarised light, from which it may, however, be distinguished by being converted into elliptically polarised light when passed through an additional slice of selenite.

If we pass a beam of polarised light through a section cut perpendicularly to the axis of a uniaxal crystal, we shall see, on looking through the analyser, a series of concentric coloured rings, crossed in general by two grey crosses, one of which remains fixed, while the other turns with the analyser (Fig. 10).

These crosses do not remain constant in intensity as we turn the analyser, but in two positions of the analyser, differing by half a revolution, they coincide to form a single black cross, and in the two positions at right angles to these they unite into a single white cross.

If a piece of glass be subjected to strain and examined in a polariscope it will exhibit coloured streaks, showing that when in that condition it possesses the property of double refraction. This may be seen very well in a piece of unannealed glass, which is in a state of permanent strain. In such a piece of glass the elasticity does not vary from point to point in the same regular way as in a crystal, so that the glass does not behave like a single crystal.

This phenomenon of colorisation of doubly refracting substances when placed between the polariser and analyser of a polariscope, affords us the most delicate test of double refraction, and therefore it is that the polariscope is so essential an adjunct to the microscope of the chemist, the mineralogist, or the botanist, often giving him most valuable information on the minute structure of the substances under examination.

If a plate of rock-crystal, which is a uniaxal crystal, cut by a section perpendicular to the optic axis, be introduced into a polariscope, the plane of polarisation will be turned about this axis through an angle which is found to be proportional to the thickness of the plate of rock-crystal.

In order to observe this phenomenon we must use homogeneous light, which is light consisting of only one colour. We first adjust the analyser, so that when the plate of quartz is not inserted the beam of light is completely extinguished. If we then introduce the quartz we shall find that the light is partially restored, and in order to produce complete extinction we must turn the analyser through a certain angle. If we now introduce a second plate of quartz, or replace the first plate by one of double the thickness, we shall find that the angle through which we have to turn the analyser, in order to produce complete extinction, is just double what it was in the first case, and, in general, that the angle is proportional to the thickness of the quartz.

The same effect is produced if, instead of a piece of rock-crystal, we use a solution of sugar; but in this case it is found that not only is the angle through which the plane of polarisation is rotated proportional to the thickness of the stratum of the fluid which the beam has to traverse, but that if we keep this constant, and use solutions containing different proportions of sugar, the angle of rotation is proportional to the strength of the solution.

This affords us a method of estimating the strength of a solution of sugar, which is of great practical value, and is extensively used by sugar refiners, who use polariscopes made for the express purpose, and called saccharimeters.

Many organic liquids and solutions of other organic substances besides sugar possess the same property of rotating the plane of polarisation.

In 1845 Faraday discovered that any liquid or solid substance subjected to the action of a powerful magnet possessed, so long as it was subject to the magnetic action, a similar power of rotating the plane of polarisation of a beam of polarised light which traversed it.

POLAR ICE.

By Staff-Surgeon Edward L. Moss, M.D., R.N., late of H.M.S. "Alert," Arctic Expedition of 1875—76.

THE conclusion of Professor Nordenskjöld's marvellous voyage in the *Vega*, and the departing of the American expedition through Behring Strait along the coast discovered by our Kellett, directed public attention, in a very prominent degree, to the frozen regions of the North.

Of whatever nationality he may be, a warm welcome is sure to await the Arctic traveller in England, for his work is one that can boast of an almost unaccountable popularity. Nevertheless, it is a striking fact, that in spite of this popularity the simplest physical conditions of the region explored remain, to say the least, unfamiliar. Perhaps if narratives of Arctic travel were less interesting they might have been more instructive. Our attention is absorbed by the spirit-stirring adventures and catastrophes of which such books are full, and the descriptions of natural fact having little in experience to appeal to, fail to be realised, and are forgotten. At all events, whenever the subject is touched upon, in conversation or in the newspapers, wide differences of opinion are expressed where there is either no room for any difference at all, or where conjecture, to be reasonable, must confine itself within very narrow limits.

The widest scope for speculation is generally assumed to lie in the unexplored region round the North Pole. Very much less is known of the South Pole, but no one appears to have the least doubt about its state, and opinions only seem to differ as to whether its ice-cap is more or less than six miles thick in the middle. Some peculiarities of the coast fauna and flora, and certain warm winds from the interior, have excited some speculation regarding the unexplored centre of the continent of Greenland, but even its inviting blank gives way in popular interest to the glamour that environs the Pole.

The "unknown North" has from the earliest times been looked upon as especially inscrutable and mysterious. Expeditions without number have failed to do much more than reach its threshold, and as they have not yet got to the Pole, it seems natural to conclude that they can tell us nothing about it. But in the absence of absolute demonstration we have plenty of material to enable us to form a reasonable surmise of what the successful explorer of the future may expect to see—a very essential exercise of the imagination, by-the-by, for that traveller himself! Our knowledge of the signs by the way has accumulated, and if we chose to interpret them they one and all indicate more or less clearly the physical condition of the region beyond.

Of the many land-marks that thus warn and guide the explorer, none give more unequivocal intimations than the north polar ice itself, and I therefore propose to bring its structure and distribution before the reader, and ask him to decide whether its evidence will admit of more than a single rendering.

A glance at a map (Fig. 1) will show that, speaking roundly, the great continental masses that make our hemisphere emphatically the land-half of the earth all come to an end close inside the Arctic circle. The Polar Sea thus enclosed for seven-eighths of its

circumference is open to the Atlantic in its remaining eighth (Behring Strait is too narrow and too shallow to be considered). In this gap, as the traveller sails north, he finds himself accompanied by an almost imperceptible current, or "slow indraught," of Atlantic water, carrying from the south a temperature considerably higher than the latitude would otherwise possess, but cooling rapidly. Here, accordingly, the nearest approach to the Pole may be made without meeting ice. has made us acquainted with the greater part of this navigable border, and to them we owe the significant classification of the ice, according to its thickness, into floes of one or more seasons old. But before the traveller meets ice he experiences, especially if he is near a coast, a very peculiar change in the water he is sailing in. When the warm indraught of Atlantic water is traced northward it is seen to expend its heat steadily and regularly till at a certain point it abruptly dis-

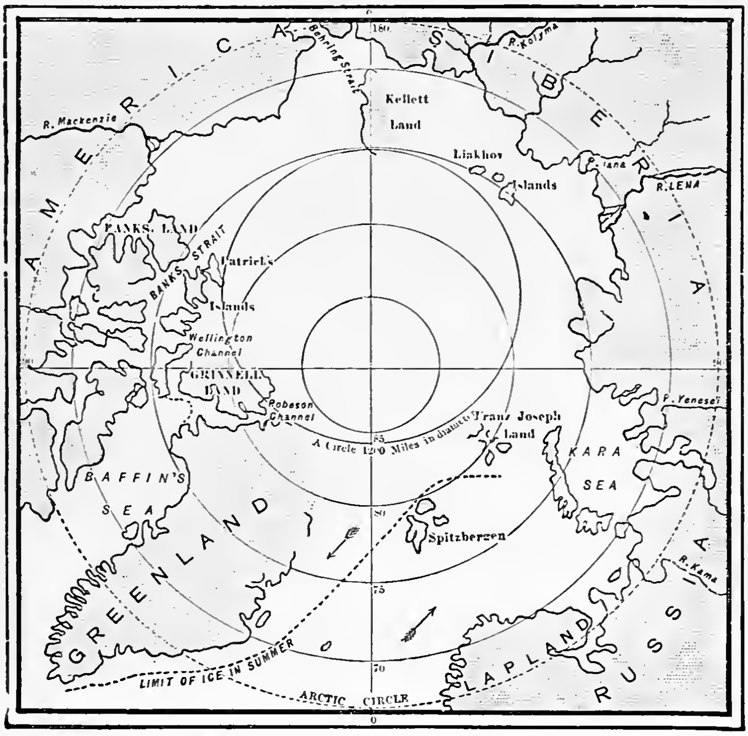


Fig. 1.—Map of the Regions within the Arctic Circle.

Sooner or later it is encountered; at first, a small decaying fragment tossed by the waves, then lines and patches of "pack," then broad fields with ice-locked pools, or "polynia"—Kingsley appropriately called them "peace pools"—and, finally, wherever these have been left behind, a wide white expanse unbroken by a single lead of water. The same order of affairs has always hitherto been found, no matter what part of the circle has been attacked—although, of course, there are many places where the district of "polynia" has not been as yet traversed. So that surrounding the unknown area there is an outlying zone, where the sea gradually gives place to ice. The enterprise of sealers and whalers following their prey into its last retreats appears from the surface, and the ship passes from water of ordinary oceanic saltness, and of a temperature still some degrees above the freezing-point, into a less salt sea with a temperature of or about 29° Fahr. By lowering down properly protected self-registering thermometers and obtaining samples of water for chemical examination from different depths by suitable appliances, it is easy to make quite certain that the warm current has not turned back, but still flows north under the cold water coming in the opposite direction; it, in fact, simply sinks because at the temperatures at which each exists it is bulk for bulk heavier than the less salt water which flows over it. The way in which the two opposing currents pass through each other

without mixing may be illustrated by the crossing of the threads in the pattern of a damask, or by interlacing the fingers and holding the arms horizontally.

A comparison of the specific gravity of the outflowing with that of the inflowing current, and a simple calculation with the co-efficients for the expansion of sea-water by temperature ascertained by Professors Thorpe and Rücker, show that to rise over even the heaviest samples of polar outflow, the Atlantic water would require a temperature above 50° Fahr. No such temperature is anywhere carried into the unknown regions, and in the sea-bed within them there is no conceivable source from which it could be supplied, since the warming power of the earth itself is utterly insignificant.

The exchange in position is, therefore, irreversible; the warm water cannot by any possibility again come to the surface, so that—postponing for the present a consideration of the fact that the sea-water comes out less salt than it goes in—we have no reason to assume that the surface of the unknown region possesses a higher temperature than that of the return current, which has meantime received all that the Arctic sun can give it, and nevertheless emerges even in midsummer with a temperature below the melting-point of snow.

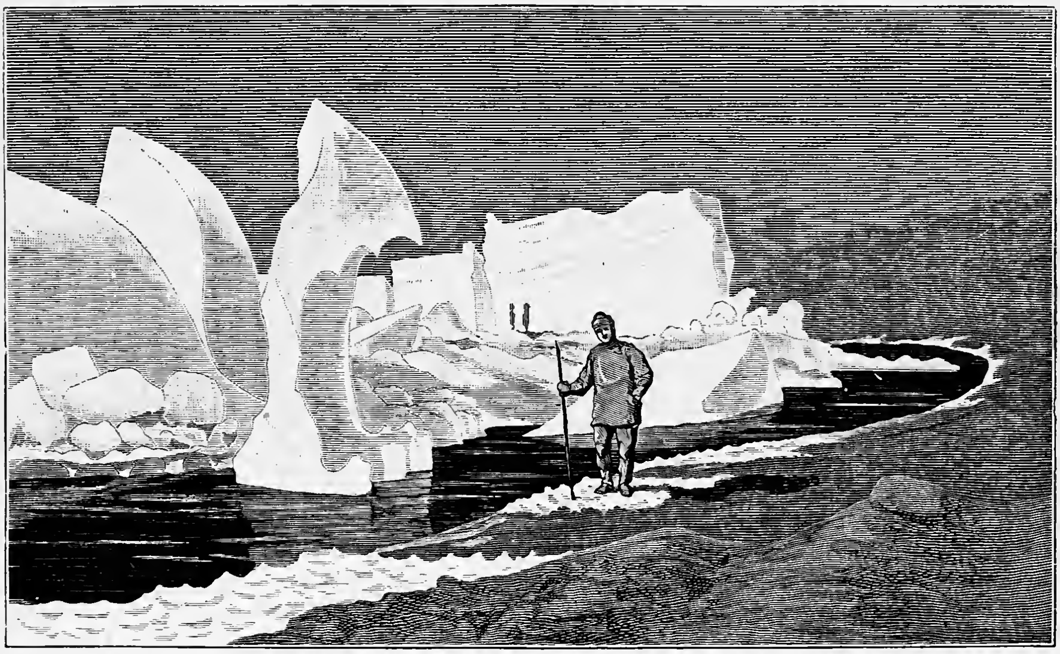


Fig. 2.—A Midsummer View on a Polar Sea, Showing the Square Stratified Blocks of Newly Grounded Floe, the Rubble of Ice Pushed before them, and also the Domed and Pie Shapes they Waste into in the Air from the Sun-heated Land.

In some places the warmer current has been traced north till it had lost all its warmth above the freezing-point without gaining sufficient dilution in exchange to make any material difference in its specific gravity; for example, our expedition of 1875-76 found it in Smith's Sound in August underlying the polar outflow at a depth of 115 fathoms with its temperature reduced to 30° 9′, while its specific gravity remained almost exactly that of average Atlantic water.

Here, in short, the traveller crosses the *oceanic snow line*, and but for the dispersive powers of wind and tide all the ice and snow to poleward of him must for ever cumber the surface of the sea. Both the dispersive agents just mentioned are, of course, effective in proportion to the space they have got to drift the ice into—the outside members of a crowd can get away easiest—and accordingly it is in the outskirts open to southern seas that they annually leave most room for the growth of new floe. Two factors take part in the formation of the new ice, namely, the direct freezing of sea-water and the accumulation of snow. When the sea freezes minute glittering scales of ice form in it, and slowly float upwards, till the surface is covered with a yielding paste several inches thick.

This soon hardens as the floating crystals raise the entangled brine into a temperature where it, too, freezes, and the floe thus formed in Nature's laboratory is salt ice, containing about one-third of the salts of the parent water. Extraordinary misstatements have been made about the freshness of sea-formed ice, because it was assumed that the water necessarily treated its salts as impurities, and expelled them in crystallising, as civilian stragglers in a military mob might be ejected were the order given to "form companies;" but the molecules of the salts in sea-water are capable, under sufficient coercion, of "falling in" with those of the water. In certain communications to the Physical Society, Professor Guthrie has demonstrated that the salts in sea-water form salt ices or "cryohydrates," as he calls them, when exposed to temperatures below 21° Fahr. In temperatures higher than this the entangled brine sometimes drains slowly out of the ice in the way described by both Sir Edward Parry and Dr. Rae; but in high latitudes the large masses remain unchanged, except on the surface, because they retain a far lower temperature all the year round. A snow-fall is usually the foundation of the new floe, and under the joint parentage of freezing sea and snow-fall it grows, if undisturbed, to a thickness of from two to nine feet. Next year, if not drifted away, it grows something less in proportion as the water is protected by its thickness, and so on, every year getting less and less from the sea, but annually receiving the snow-fall.

What, then, is the greatest thickness to which the ice thus grows, and where does it grow to its greatest thickness?

I have a vivid recollection of the surprise I, in common with some other members of our expedition, felt when we first realised the enormous thickness of the floes blocking the northern end of Robeson Channel. A floe perhaps fifteen miles across, and floating ten or twelve feet out of water, is sufficiently imposing; but a certain amount of scepticism attends the calculation that there is at least eight times as much of it below. Afterwards, for many months, we saw the edge of the eastward-drifting pack that filled the whole sea ground along the shore in seven fathoms and upwards, and sometimes crush inward till its entire section was exposed, or only hidden at the base by the tumbling rubble of ice, or the bastions of sand it pushed before it (Fig. 2). Such ice was not to be found in land-locked bays, into which it could not drift from the sea, nor was it confined to any one spot—our sledges followed its edge for 300 miles along the shore of the Polar Sea. If we had read the records of previous expeditions with greater care, the stupendous character of the ice would not have been unexpected. It is by no means novel. Ten degrees west of the farthest point reached by our sledges under Commander Aldrich, Sir Edward Belcher encountered it 106 feet thick, drifting into and grounding on the shores of Wellington Channel. Twenty degrees further on Surgeon Fisher of the *Hecla* and *Griper* reports floes 90 feet thick. Another 10° brings us to the coast of Prince Patrick's Island, where Sir Leopold M'Clintock notes, like Aldrich, how the edge of the tremendous pack rested on the ground two miles out to sea. Lieutenant Mecham following it west to Banks Strait, figured the huge "blue-domed" floes in the Parliamentary reports of 1855. It was in Banks Strait that Sir Edward Parry was finally stopped by the great undulating floes, reaching 102 feet in thickness, that he tells us he had never seen in Baffin's Sea, or in the land-locked channels he had left behind him, but which filled the whole sea before him. M'Clure also remarks that the polar ice is not found in the channels of the Parry group. "That," he says, "which fills these bays and is carried down Barrow Strait is the comparatively small ice which drifts from its southern edge." Here the *Investigator* reached her farthest point, after following the edge of the same "stupendous pack" the whole way from Behring Strait, 1,000 miles to the west. Her records are full of references to enormously heavy ice. M'Clure tells of a "huge and solid floe 29 feet over water, and grounded in 29 fathoms." Sir Alexander Armstrong mentions ice 92 feet thick, and remarks that such floes are doubtless the edge of "that pack which extends uninterruptedly from shore to shore of the Polar Sea."

As the *Alert* wintered inside the shelter of its grounded edge at "Floeberg Beach," so the *Hecla* and *Griper*, *Investigator* and *Enterprise*, sheltered inside the "barrier" of grounded fragments of floe, which, to adopt Parry's words, "for distinction sake we called bergs." North of Behring Strait the same ice, floating "compact as a wall, ten or twelve feet high at least," stopped Captain Cook in August, 1778. We again recognise it all along the north coast of Siberia, in the "Toroses" or "Adam's Ice" of the fur-hunters, often grounded in lines five miles from shore. The great floes met by the Russian expeditions to the north under Admiral Wrangell with "conical hills, some of

the largest 90 feet high, and long round valleys between them," are precisely what Mecham figured in his journal, and Parry, north of Spitzbergen, described as floes covered with "smooth regular cones." These were only too familiar to our sledge travellers. Wrangell in his introduction mentions ice in the north of the Kara Sea 200 feet in thickness; and finally, to complete the circle, the floes that turned back Franklin in his attempt to push north in the Spitzbergen seas, are identified by Admiral Beechey and Messrs. Fife and Allison as the same stupendous fields they saw off Melville Island and Banks Land.

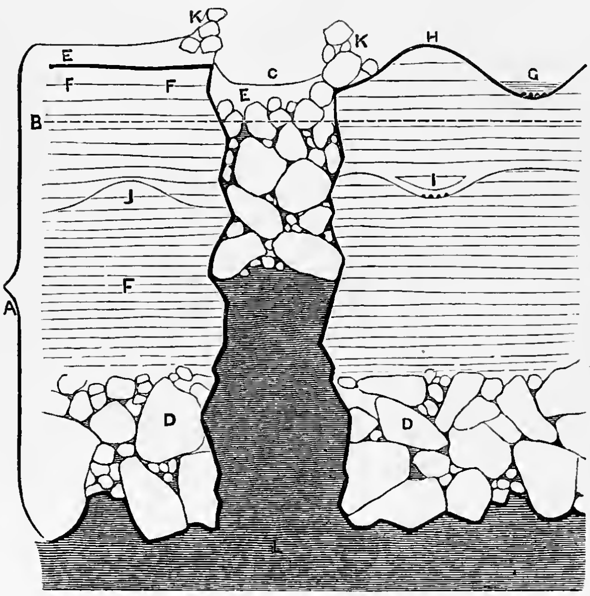
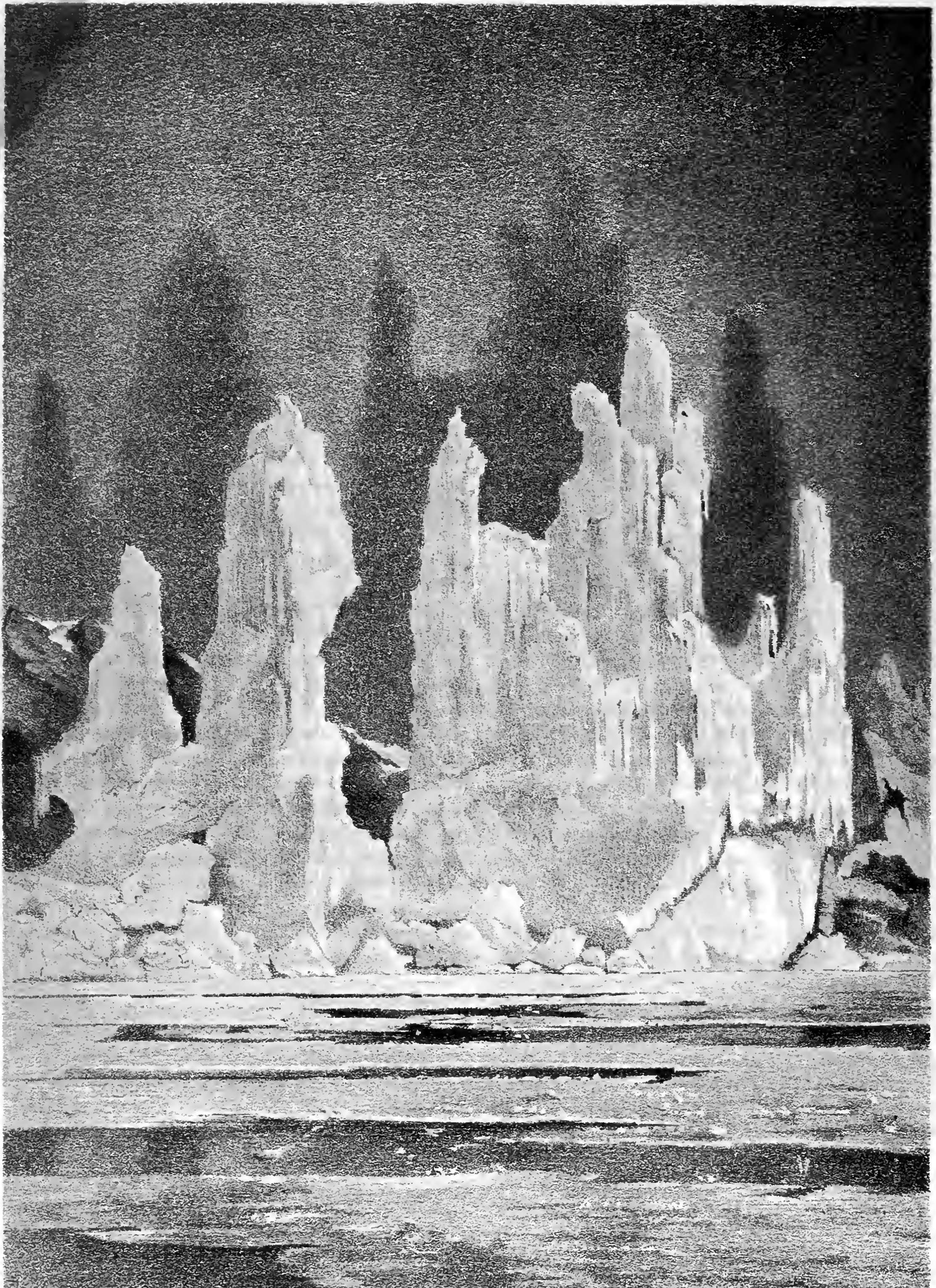


Fig. 3.—Diagrammatic Section of Polar Floe.

(A) Section of the Floe; (B) Sea Level; (C) Fissure filled with fragments freezing into (D D) Conglomerate or "porphyritic" ice of Parry; (E E) Annual Snow subliming into (F F) Stratified Ice; (G) Superglacial Pool; (H) an "Ice-cone" or "Blue-top"; (I) a "Fossil" Superglacial Pool; (J) a Fossil "Blue-top"; (K) Boulder Ice crushed up from fissure into lines of "hummocks"; (L) Polar Sea.

We thus see that ice of a thickness not met with in the outlying zones where annual floe forms, has been reported at every side of the circum-polar circle, and always on the limit of the unknown area. A study of the structure of this ice tells in the most unmistakable language how it comes to be there; and our expedition had unprecedented opportunities for studying fresh cleft surfaces, unchanged by the disintegration of summer. When we examine the section of a floe (Fig. 3) freshly cleft and pushed out of water, it is seen to be faintly, but nevertheless perfectly distinctly, stratified in even parallel bands about a foot deep. The stratification is best seen from a little distance; the blue surface of a section shows regular horizontal lines of darker or lighter shade, depending on whether the air-cells in the transparent ice are far apart or close together and numerous. The strata are deepest at the top of the section, and grow thinner towards the bottom. We saw similar stratification in true land-grown icebergs from Petermann's Glacier, and Payer has described the same in the glaciers of Franz Joseph Land; in short, it is precisely the same in character and source as that of the névé or ice-field of annually accumulating snow that lies in the basins of mountains, and pours down as glacier in better known parts of the world. Occasionally the strata may be seen curving and thinning out over some inequality beneath them, and sometimes they are interrupted by a lense-shaped patch of olive-tinted ice marking the section of what was once a pool on the surface of a floe, but which has frozen and been gradually buried under layer after layer of annual snow (Fig. 3). An irregular line of little black dots often occurs along the bottom of such fossilised superglacial pools, and when they are microscopically examined each little dot is seen to be a speck of dust, consisting of the remains of certain primitive plants that live on the surface of snow and in such pools, mixed up with a peculiar red inorganic sand which has been found by Parry, M'Clintock, Koldeway, and others, strewn on floes far from land. This contains magnetic particles, and is generally attributed to either a volcanic or meteoric source.

The conversion of each season's snow into a layer of ice does not depend upon any process of thaw, and as it occurs within a foot or two of the surface, it is plain that pressure has little to do with it. It can be traced through every stage, the greater part of the snow falls as an almost impalpable powder, consisting of hexagonal plates and needles, although in the milder weather of spring and autumn it appears in more complicated and often extremely beautiful stars. After a time the crystals most exposed to the cold grow larger; these are of course on the top in autumn, and at the bottom in summer. The latter soon grow to resemble hailstones, then unite into irregular lumps and rods like sugar-candy, and finally coalesce into spongy ice. The cause of the growth is easily understood when we reflect that ice crystals evaporate without melting, and that the snow always finds itself interposed between widely differing temperatures. The molecules thrown off in the evaporation of the comparatively hot crystals settle down on the colder ones where they



THE EFFECTS OF THE SUNS RAYS ON AN ICEBERG.

have less thermal vibration; the process in short is simply one of *sublimation*.

In the regions of annual ice, great masses are sometimes formed by the sliding up of one sheet over another. A section of such a mass no doubt exhibits a stratification, but it is without the progressive thinning from above downward, or the bending or interruptions of névé layers; and no one contends that the latter, or the stratification of icebergs, or of the great Antarctic ice-cap is thus produced, and there cannot be the least question that the stupendous floes owe their origin to the annual accumulation of snow-fall.

But it may be asked, If the precipitation of the Pole thus accumulates on the sea, and remains unmelted, how does it happen that the outflowing Arctic currents are less salt than those that flow in? An examination of the outflowing current supplies an answer. If it did not, we should be obliged to rely only on the evidence given by the stratification, and it would appear to be in contradiction to that of the outflowing current. An analysis of the latter shows that there is something more than the additional water to be accounted for, namely, a considerable increase in the sulphates. A precisely similar state of affairs is to be met with in the currents entering and leaving other enclosed seas: the Black Sea affords a familiar example. Its outflow has long been known. Homer mentions it ("Iliad," II., 845), and Shakspere makes Othello say—

> "Like to the Pontic sea,
> Whose icy current and compulsive course
> Ne'er feels retiring ebb, but keeps due on
> To the Propontic and the Hellespont."

The existence of an underlying warm stream of salter water has been proved by Captain Wharton of H.M.S. *Sheerwater*, and the analyses of Forchammer have shown that the less salt outflow has, like the Arctic current, a greater proportion of sulphates. In the case of the Black Sea, the source of both the water and the sulphates is palpably the precipitation of the land carried down by the great rivers, and we may reasonably suspect that the sulphates in the Arctic outflow indicate its shore origin; and we have, moreover, the confirmatory fact, that if it is not altogether confined to the neighbourhood of land, it is at all events strongest there.

Snow melts on Polar shores, and remains on Polar sea, because ice is transparent to radiant heat, but yields to heat from an obscure source. The rays of the Arctic sun falling on the floes, waste themselves in their icy depths, unless, where here and there on the broad solitude of snow there may be a speck of algæ, or a point of dust to catch and transfer them, then the tiny speck sinks into a little watery pit, and the water, less diathermic than the ice, spreads itself in a super-glacial pool, and perhaps cuts a river-bed, leaving the well-known undulating hills of blue stratified ice on either side of it, till it plunges into some fissure between the floes. But on land the conditions are widely different, and as a result we have the striking contrast that the end of summer afforded us at Floeberg Beach—a land bare of snow, and a sea covered with it. To play the part of the little speck of dust, there is the whole surface of the ground which the transparent snow fails to hide from the sun, and accordingly the snow melts from below with amazing rapidity, and soon rushes along between the shore and the ice barrier, heaping up long parallel mud-banks against the latter, loosening the sea-ice, and sweeping fragments from its edge southward through every channel.

Since the conditions favouring the melting of snow are most abundant and active near shore, and since the chief source of waste from the great polar névé is the drifting away of its marginal fragments into the Atlantic, we must look for its centre as far as possible from both. A point between the Pole and Behring Strait best satisfies these requirements. It is plain that if nothing interfered with the perennial accumulation of snow, the floes would soon rest on the bottom of the sea; but changes of temperature, tide, and wind, and the contact of the ice-fields with the land, fissure the floating crust, and as soon as a fissure opens, the space is immediately filled with a chaotic rubble of floating fragments torn from the depths of the sides—these, freezing together, form the "porphyritic ice" of Parry as a foundation for fresh snow deposit, and effectually prevent reclosure, so that there is a constant removal of the névé from the centre outward.

Perhaps some reader who has accompanied me so far as exploration has gone, may be inclined to halt, when I invite him to launch into conjecture about a region as yet totally unexplored; something will, however, have been accomplished if he can lay before his mental vision a truer picture of what is already known of the farthest north. Our conceptions of the polar pack have been too long built up out of the glassy ice of frozen pools and skating rinks, while we might have found a truer presentment of it in Alpine névé and glacier.

But if the evidence of the ice is accepted as reasonable, the physical condition it points to is not totally without a parallel; it merely means that the northern ice, though at present reduced to comparatively small dimensions, is essentially the same in origin as that which now covers the South Pole.

Each ice-cap, as Dr. Croll explains to us, must alternately wax and wane through enormously long periods of time, and in each we see the beginning of that freezing-out process, which, if we are to believe either geologists or mathematicians, the slow cooling of the sun must eventually inflict upon the earth.

RUBIES AND SAPPHIRES.

By F. W. Rudler, F.G.S.,

Curator of the Museum of Practical Geology, London.

ONE of the many high-sounding titles assumed by the King of Burmah is that of "Lord of the Rubies." Next to a white elephant, a ruby of unusual size is probably the most valued possession pertaining to Burmese royalty. The finest rubies in the world are found within the territories ruled over by King Theebau, and it is believed that among his treasures there are specimens of the gem far finer than any upon which the eye of European has ever gazed. This passion for rubies is not, however, peculiar to Burmese potentates, but is indulged in, to a greater or less extent, by most Orientals. Nor is it by any means a fashion of modern growth. If the translators of the Old Testament are to be trusted in their use of the word "ruby," the value of the stone must have been clearly recognised in the East at least as far back as the days of King Solomon and of the author of the Book of Job. When these Hebrew writers are searching for the type of all that is most costly, it is the ruby that they select; and hence the well-known passages in which wisdom is extolled above rubies. From the days when those passages were penned down to our own times, the gem has continued to stand in the first rank among precious stones; and even in the London market at the present day an Oriental ruby of fine colour and of moderate size will command a far higher price than any diamond of equal weight.

If the reader will take the trouble to visit any large collection of minerals, such as that in the British Museum or that in the Museum of Practical Geology, he will find that the specimens of ruby are placed alongside the specimens of sapphire. Yet what can be more different than these two stones—the ruby of a brilliant red colour, the sapphire of a bright blue? It needs, however, but the slenderest acquaintance with chemistry to prove that there is here no outrage upon the scientific principles of classification. It must be remembered that the colour of a mineral is in most cases a mere accident, and it were indeed a frail system of classification that could be raised upon such a basis. Sometimes, it is true, colour offers a valuable clue to the identification of a mineral; but just as often, or perhaps oftener, it proves utterly valueless as a distinctive characteristic. If a number of minerals are to be sorted, so that those of a like kind may be placed together, the great object to be kept steadily in view is their chemical composition. To this point everything else is subordinate. If two substances are found to have the same chemical constitution, we are bound to recognise their kinship, notwithstanding any difference in colour or other physical features. Now the ruby and the sapphire, in spite of their marked differences in colour, are pronounced by the chemist to be one and the same thing in essence, and it is for this reason that they are coupled together at the head of this article. Both of them are, in fact, natural forms of that particular kind of matter which the chemist terms *alumina.*

Rather more than twenty years ago an eminent French chemist succeeded in preparing, on a commercial scale, a metal which had previously been regarded only as a chemical curiosity, and was utterly unknown outside the laboratory. This was the metal *aluminium.* Every one is now-a-days familiar with the brilliant white metal, so much like silver in colour and in lustre, yet so different from silver in many of its properties, especially in its extreme lightness. If a piece of silver weigh ten pounds, exactly the same bulk of aluminium will weigh only about two pounds and

a half. This lightness, together with the beautiful colour and the durability of the metal, led to the prediction, when it was first brought into the market, that aluminium would soon find a multitude of uses in the arts. Experience, however, has not justified this prediction, and at the present time its use is principally restricted to trivial purposes of ornament, and to the preparation of a copper-alloy, singularly like gold in colour, known as *aluminium bronze* or *aluminium gold*, itself employed in the manufacture of pencil-cases and other ornamental objects.

It is matter of familiar observation that most of our common metals when exposed to the atmosphere lose their brilliancy, and that a thin film of tarnish or rust gradually creeps over their surface. This rust is in most cases a metallic oxide, produced by the union of the metal with the oxygen of the atmosphere. Aluminium, however, may be exposed for a long time to atmospheric influences without formation of an oxide, and in this power of resistance it is almost like one of the precious or so-called "noble" metals. Nevertheless, aluminium is capable, under certain conditions, of combining with oxygen, and it then produces an oxide which is known to the chemist as *alumina.* It is this substance which, in a pure crystallised condition, forms the ruby and the sapphire. These gems are therefore, in chemical language, *oxides of aluminium.*

To those who are strangers to chemical ideas it may seem incredible that the beautiful silvery metal aluminium should be contained in a substance so extremely different as a ruby or a sapphire, yet it is beyond question that these gems contain more than half their weight of the metal. The same silvery metal is also found in *alum,* whence, indeed, comes the word "alumina." Still more surprising is the fact that this metal is likewise a constituent of common *clay.* Every clod of clay contains from fifteen to twenty per cent. of aluminium, and hence this metal is sometimes described as "the base of clay." Such an expression is quite allowable; but it unfortunately happens that popular writers frequently go farther, and speak of the ruby and sapphire as "crystallised clay." As this is a grave error, it is necessary to point out the great chemical difference between the clay and the gems. The ruby and the sapphire are simply oxide of aluminium, coloured with traces of other metallic oxides; while the clay is a substance of complex composition, varying in different kinds, but consisting when pure of a silicate of aluminium combined with water. It will thus be seen that aluminium is the metallic basis of both bodies, but that in one case it is present as an oxide, and in the other case as a silicate.

In the ruby and in the sapphire the alumina, or oxide of aluminium, is always in a crystallised condition. So much of the article on Diamonds* was occupied in explaining the phenomenon of crystallisation, that it is needless to add another word on that subject. The crystals of alumina are marked by a six-sidedness which brings them into close kinship with the forms of rock crystal described on page 189. A very characteristic shape of a crystal of alumina is represented in Fig. 1. Here is a crystal made up of two similar halves, joined together base to base, each consisting of a tapering pyramid with half a dozen sides. It is notable that these crystals, instead of being sharply cut, so as to present faces which are quite flat and edges which are quite straight, are frequently more or less rounded, as though they had been rolled and rubbed among pebbles in the bed of a stream. The worn appearance which they then present is indicated in Fig. 2.

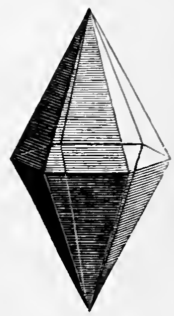


Fig. 1.—A characteristic form of Crystallised Alumina.

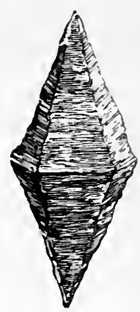


Fig. 2.—A Rolled Crystal of Sapphire.

Mineralogists are in the habit of including all varieties of crystallised native alumina under the general name of *corundum,* a word which has crept into our scientific vocabulary from the East. In most cases the crystals of corundum lack transparency, and possess only dull colours, but when they happen to be clear and of bright tints they form some of our most highly prized gem-stones. It is the red varieties of corundum that form the *ruby,* and the blue varieties the *sapphire.*

Occasionally the corundum presents other colours, and it is then named after the stone to which it most nearly corresponds in tint, from which it is distinguished, however, by the qualifying designation "Oriental." Thus, a green corundum resembling the emerald in colour is known as *Oriental emerald,* a yellow corundum looking like a topaz is called *Oriental topaz,* while a purple

* "Science for All," Vol. II., p. 187.

corundum having the colour of amethyst is distinguished as *Oriental amethyst*. Sometimes the red varieties are termed *Oriental ruby* to distinguish them from other red stones known also in trade as "rubies," but far inferior to the true ruby in colour, hardness, rarity, and therefore in value. But when the term "ruby" is employed without any qualifying designation, it is, or should be, the red corundum, or Oriental ruby, which invariably is intended.

It is from India that our supply of the different kinds of corundum is principally derived. Ceylon yields a great variety of specimens in the form of rolled crystals, among which the blue sapphires are most abundant. Of rubies, or red corundum, the finest varieties are obtained from Burmah, but very little is yet known as to their mode of occurrence. It is said that they are found in a bed of sand or gravel which is systematically explored. The workings are guarded with the strictest jealousy, no European being allowed to visit them. All stones exceeding a certain weight are claimed by the king, and hence when a large stone is found it is the policy of the finder to break it up into a number of fragments.

In 1871 a remarkable deposit of corundum was discovered by Colonel Jenks in North Carolina. Instead of occurring, as it commonly does elsewhere, in the form of water-worn crystals or rounded pebbles, the corundum was here found in its actual matrix or mother-rock. Veins of corundum running through serpentine rocks yielded crystals of enormous size, some of them weighing more than 300 lbs. each. It was, of course, not ruby and sapphire that was thus found by the hundredweight. Much of the mineral was, indeed, merely coarse corundum, and could be used only for the purpose of polishing other stones, but still some of it was sufficiently bright in colour to be cut as ornamental stones.

Those varieties of native alumina which are not fine enough to be utilised by the jeweller are yet useful, by reason of their excessive hardness, as abrading agents. The extreme hardness of corundum furnishes, indeed, one of the most distinctive characteristics of "Oriental gems," such as ruby and sapphire. Next to the diamond, corundum is the hardest known mineral. It can therefore scratch every other stone, but is itself scratched only by a diamond. Incidentally it may be remarked that the substance so well known as *emery* is a very impure form of alumina, and is therefore closely related to the coarser kinds of corundum.

In the study of minerals it is so important to note their hardness that the first thing a mineralogist generally does, when an unknown substance is presented to him, is to take out his penknife and observe whether he can scratch it or not. Sometimes, to be sure, a crystal is not uniformly hard on all its faces, but as a rule the hardness is subject to little or no variation on different parts of the same crystal, or on different crystals of the same substance. A property which is at once so characteristic and so easily examined must obviously be of great value in the discrimination of minerals; and accordingly a table has been drawn up in which the degrees of hardness of a few typical minerals are expressed by numbers, thus forming a standard scale to which the hardness of any other substance may be referred with tolerable precision. The table which is universally accepted by mineralogists was originally drawn up by an Austrian named Mohs. The highest degree of hardness, monopolised by the diamond, is denoted in Mohs' scale by the figure 10. The next degree of hardness, No. 9, is assigned to the ruby, sapphire, and other varieties of corundum, and serves at once to distinguish these stones from others with which, by similarity of colour, they might readily be confounded. Thus an Oriental or true ruby is easily distinguished from other red stones, such as a spinel-ruby or a garnet; and in like manner an Oriental emerald, or green corundum, is separated from an ordinary emerald, and an Oriental amethyst, or purple corundum, from an ordinary amethyst. All these "Oriental" stones, or coloured corundums, have the same high degree of hardness, trivial differences excepted. It is said, for instance, that the sapphire is slightly harder than the ruby.

Another character which serves to distinguish corundum from most other minerals with which it is likely to be confounded is its high specific gravity. This expression, in constant use by mineralogists, merely indicates the relative weight or *gravity* of different kinds or *species* of matter. If we say that an Oriental ruby has a higher specific gravity than a spinel-ruby, we simply mean that if equal bulks of the two bodies be weighed, the Oriental stone will be the heavier. There is no characteristic of greater service to the mineralogist, especially in the discrimination of gem-stones, than this character of specific gravity. Suppose it is required to determine whether a given stone of red colour is an Oriental ruby or simply a spinel, or maybe only a garnet; it is true that crystalline characters will at once serve as distinctive marks,

since the six-sided forms of ruby are unmistakably different from the crystals of spinel or of garnet, minerals which belong, like the diamond, to the cubical system. Fig. 3 represents the common form of a spinel-ruby, and Fig. 4 one of the most characteristic forms of garnet. No true sapphire or ruby ever assumes either of these shapes, or anything like them. But when a stone has passed through the hands of the lapidary its crystalline form is lost, and is therefore no longer available directly as a test. Recourse must then be had to some other diagnostic or distinctive character. Hardness is here of service, for both spinel and garnet are softer than the true ruby. It is not always desirable, however, to attempt to abrade the surface of a finely-cut stone, nor is the test easy of application in the case of very hard stones. It is then that we may turn with confidence to the test of specific gravity. To apply this test, we weigh the stone first in air in the ordinary way, and then in water by suspending it beneath a scale-pan and immersing it in the liquid, as shown in Fig. 5.

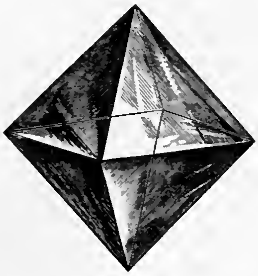


Fig 3.—A common form of Spinel Ruby.

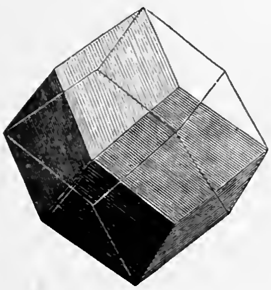


Fig 4.—A common form of Crystal of Garnet.

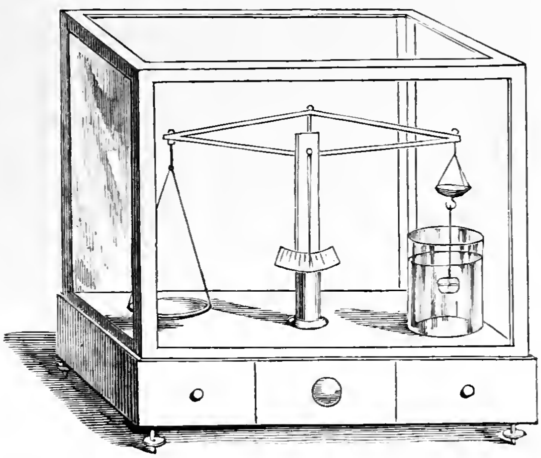


Fig. 5.—Hydros'atic Balance, or Apparatus for determining the Specific Gravity of a Solid Body.

It is a familiar fact that a stone when plunged beneath the surface of water appears to lose weight. A boulder on the sea-shore may be too heavy to be moved by a man, yet when immersed in water it may be so buoyed up as to be moved with ease. In the same way, a cut gem-stone plunged into a vessel of water becomes lighter; and according to a well-known principle, said to have been discovered by the famous Sicilian philosopher, Archimedes, the loss of weight is precisely equal to the weight of a quantity of water occupying the same bulk as the submerged stone. Now "specific gravity" means neither more nor less than the weight of the body compared with the weight of an equal bulk of water. All we have to do, therefore, in order to obtain the specific gravity of the stone in question, is to divide the weight of the stone in air by the loss of weight which it suffers when placed in water, and the quotient gives at once the specific gravity. By this simple bit of arithmetic we find that the Oriental ruby has a specific gravity of about 4; in other words, the stone is four times as heavy as an equal bulk of water. A cubic foot of water weighs, roughly speaking, 1,000 ounces; therefore, if it were possible to procure a cubic foot of ruby or of sapphire, or of any other kind of corundum, it would weigh about 4,000 ounces. But the same bulk of spinel-ruby or of garnet would weigh considerably less, since the specific gravity of the former is about 3·5, and that of the latter 3·8. Here, then, is a simple yet unfailing test, by means of which we need never be in doubt about the nature of the stone under observation. It is worth noting, however, that some of the coarser varieties of corundum do not possess exactly the same specific gravity as the finer kinds which are used as gem-stones.

Occasionally the term *density* is used by mineralogists in the place of *specific gravity.* Strictly speaking, the two expressions are not quite identical, for while specific gravity means relative *weight,* density means relative *mass.* It is unnecessary, however, in this place to dwell upon this refined distinction, and as a matter of fact mineralogists are in the habit of employing the two terms indifferently.

Before quitting our study of the physical properties of the ruby and sapphire, attention should be called to a peculiar optical appearance which is presented by certain varieties of these gems, especially those of a greyish-blue colour and cloudy aspect. When stones of this kind are cut with a rounded surface, or, as jewellers say, *en cabochon,*

they are found to exhibit on the surface of the boss a luminous star, generally of six rays, whence they are called *star-sapphires.* If the stone be perfect, the rays of light stream forth from the summit of the dome, which coincides with the centre of the star; but it often happens that the position of the star is not truly central.

When a star-sapphire is carefully examined it is generally found to present on its surface a number of concentric lines, running in six-sided forms, and indicating a lamellar or platy structure in the stone. It is upon this peculiar structure that the phenomenon of *asterism*, or the optical appearance of the star-stones, necessarily depends. The phenomenon may indeed be imitated on a convex piece of glass by ruling a multitude of fine parallel lines in proper directions. If these lines run all in one direction they will give rise to a band of light

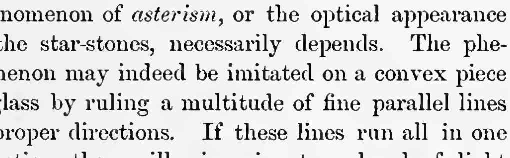


Fig. 6.—Diagram illustrating the artificial production of Asterism.

running across them transversely, as shown in Fig. 6, A. Such an appearance is presented by many stones which have a fibrous structure, especially when they are cut into the form of a boss, or *en cabochon*, whence they are commonly called "cats' eyes." Now if a second set of fine parallel lines be drawn at right angles to the former set, a second band of light will be produced, and the combined effect of the two sets is the production of a luminous cross, as represented in Fig. 6, B. If instead of two sets of transverse lines we rule three sets, cutting each other at angles of sixty degrees, so as to form by their intersection a multitude of little equal-sided triangles, there will necessarily be three bands of light, and by their crossing each other they form a star of six rays, as seen in Fig. 6, C. This is exactly similar to the appearance presented by the star-sapphire, and there can be little doubt that the phenomenon in the stone is due to a similar cause—namely, to the reflection of light from three sets of intersecting lines naturally existing in the stone, and closely connected with its crystalline structure.

This property of asterism was certainly known to the ancients, who speak of the star-stone under the name of *asteria*. It is probable, however, that other stones, such as the cat's eye, were likewise known under the same designation. The term "sapphire," or some kindred word, appears to have been applied to a number of distinct stones of blue colour. At any rate, it is certain that the sapphire of the ancients was in many cases a very different stone from our modern sapphire. Greek and Roman writers on natural history, such as Theophrastus and Pliny, tell us distinctly that the sapphire is "spotted with gold." Now, such a description is utterly inapplicable to the blue corundum, but applies well enough to the stone known as *lapis lazuli.* This is an opaque mineral of bright blue colour, which is commonly veined and spangled with a mineral of brassy or golden colour, called *iron pyrites.* It is consequently believed that some at least of the ancient "sapphire" must have been our lapis lazuli—a stone which is still valued for ornamental purposes, but is totally distinct, chemically and physically, from our sapphire.

In the course of this article the reader has been introduced, perhaps unconsciously, to the idea of a *mineral species.* By studying the ruby and the sapphire we have seen which characters are essential and which are accidental, and have thus been led to conclusions which run counter to popular notions on the subject. In examining an unknown mineral, the first thing is to settle its chemical composition, and the next is to study the character of its crystallisation. Bodies which have the same chemical constitution, and which crystallise in the same system of forms, must necessarily be ranked as one and the same species. Neither chemical composition nor crystalline character is alone sufficient to establish a species. If, for example, two bodies contain the same elements united in the same proportions, and are therefore chemically identical, but if they assume forms which are crystallographically incompatible, they are invariably regarded as belonging to distinct species. Thus it was shown in a previous article that diamond and graphite are almost identical in chemical composition, but yet crystallise in two distinct systems; hence they form two mineralogical species. Ruby and sapphire, on the contrary, agree both in composition and in crystallisation, and therefore belong to the same species. Minor characters, such as colour, are only sufficient to constitute differences of *variety*, not of species; and thus it comes about that the red ruby and the blue sapphire form two *varieties* of the *species* corundum.

When a mineralogist has determined the composition and the crystallisation of a given mineral, he proceeds to examine its other properties, such as density, hardness, colour, lustre, and so forth. Two

of these characters—specific gravity and hardness—are capable of quantitative expression, accurately in the first case, and approximately in the second. We not only say that one body is denser and harder than another, but we can say exactly how much denser, and in rough terms how much harder. When we read in some technical treatise on mineralogy that corundum has a S.G. 4 and H. 9, we learn—first, that the specific gravity (S.G.) of the mineral is represented by 4, or, in other words, that it is four times as heavy as an equal bulk of pure water; and secondly, that its degree of hardness (H.) is represented on Mohs' scale by the figure 9, that is to say, that it is softer than diamond, which has a hardness of 10, but harder than topaz, which has a hardness of 8.

It will have been gathered from the foregoing remarks that the science of mineralogy is largely dependent upon a number of collateral sciences. A mineralogist, so far from being an independent individual, is constantly seeking aid from his fellow-labourers in other scientific fields. He requires a knowledge of chemistry to determine the composition of the bodies which he examines. He needs familiarity with crystallography to describe their forms, and a knowledge of physics to take their specific gravities and to examine their optical properties; while the study of geology is essential if he desires to know anything about the mode of their occurrence.

Mineralogy, in fine, furnishes an admirable illustration of the interdependence of the physical sciences. The several sciences are but so many members of one grand system, dovetailed together in such a way that each supports, and is in turn supported by the rest. It is absolutely impossible to isolate any single science, and to study it apart from all others.

WEATHER TELEGRAPHY.

By William Liscombe Dallas,

Meteorological Office of the Board of Trade.

THE action of the Meteorological Office in issuing, through the various newspapers, forecasts of the weather for a day in advance has attracted a good deal of attention, and occasioned considerable speculation as to the possibility of accurately foretelling approaching weather in our changeable climate. The general newspaper reader is doubtless quite unaware of the anxiety with which the probable weather and wind for each separate district are forecasted, because in nearly every case he or she has only a cursory acquaintance with the atmospherical phenomena which influence our weather changes, and is consequently unable to comprehend the reasons on which the forecasts are based. Some explanation of the materials which are available in order to enable us to form a judgment as to the probable weather may, then, be acceptable, as by these means it will be possible for the reader to follow intelligently the line of thought travelled by the forecaster, and thus to see how easily failure may occur.

The extraordinary strides which have been made in the different sciences during the past century are owing probably more to the general interest which has been awakened in their study among all classes of the population, than to the individual labours of single *savants*, however eminent. It is, therefore, subject for congratulation that by means of weather telegraphy a mode of popularising the study of meteorology has been found, and a prospect opened up of arousing the science from that dormant condition in which it has so long remained. While meteorology is engaged in attempts to solve the problems of the generation and action of different well-known atmospherical phenomena, weather telegraphy, taking these phenomena and their surroundings as established facts, makes use of them as the basis for weather forecasting, without attempting any explanation of their origin or destiny, and without adopting any of the many theories extant as to their nature. With such accuracy is this done, that at the Glasgow meeting of the British Association in 1876, Dr. Andrews congratulated the scientific world, that, having regard to the little progress meteorology had made as a science, the returns of weather telegraphy might be considered to be on the whole decidedly satisfactory. Before attempting an explanation of the physical properties of the different atmospherical phenomena, it is necessary to have a perfectly clear understanding of the meaning of the terms employed, and of the different attributes of the principal phenomena.

It will be noticed that certain dotted lines appear every morning on the chart; these lines are called isobars (*i.e.*, equal pressure), and have figures attached to them, showing what is the height of barometer in those parts of the countries over which they pass. They are drawn over the country in such a manner, that a barometer placed under any one of the lines will, at any part of its course, register exactly the same pressure. From want of information—it being practically impossible to obtain observations from every part of Europe—the isobars, it will be seen, sweep over our area, perhaps without touching even one of the stations; but their course may be taken as approximately correct, pressure varying regularly between the different stations, so that by a careful measurement between the nearest points, the position of the isobar may be fixed almost with certainty. For example, suppose the reports from Plymouth and Portsmouth gave the barometer reading as 29·4 in., while those from Bristol and London were each 29·2 in., then the line 29·3 in. might be drawn with certainty midway between the two southern and two northern stations. These lines, therefore, show at a glance the general height of the barometer, or, speaking more correctly, the general distribution of atmospheric pressure over the country, and a knowledge of the conditions which usually accompany the different distributions and relations of these isobars, and of the movements usually followed by the different systems, is the groundwork of the study of the weather.

The pressure of the air varies considerably over a large area at the same time; it consequently follows that at a certain place, at a given time, pressure is lower than in any other region. Now, if the observations of the height of the barometer, taken simultaneously at a number of stations scattered over the country, are plotted on a chart, the region of lowest pressure will be readily visible, and also the manner in which the barometer rises on all sides of it. Let it be supposed that a number of synchronous observations have been received from all parts of the area covered by the Meteorological Office chart, and that on a given day the lowest reading of the barometer be 28·55 in. over Central Wales, then, as pressure is increasing on all sides of that spot, at a short distance all round, places will be found where the barometer stands at 28·6 in. exactly. These places we will now connect together by means of an isobar, and so a small circle is formed. Still farther off, but still in a more or less circular form, observers will report the barometer as reading 28·7 in., and so a larger circle will be formed; and this proceeding may be repeated till the highest readings are reached. It will always be noticed, however, that the outer lines are not so regular as the others, that they have merely a curved instead of a circular course, and that the exterior ones of all, instead of bending round the low pressure, bend perhaps in the reverse direction, and appear to embrace another space outside, probably, the limits of the chart. The space enclosed by the line of least value is called an area of low pressure, or, on account of its winds, a cyclone, while that which the isobar of greatest value encloses is called an area of high pressure or anticyclone, and it is on the relation which the winds bear to these areas, and which the areas bear one to the other, that the changes in weather depend. How they are formed is a doubtful point, and their rate of motion is variable; but certain facts are known about them, which, when fully understood, enable the student to form very often a correct conjecture as to the approaching weather. This we opine is the idea with which the general public view the establishment of meteorological bureaux, and to be able to say, with some approach to certainty, when a flood of rain will cease, or when a grateful shower will moisten the parched land, would, to most people, be the acme of the science, albeit there may be very little of what some call "science" in it.

Both "cyclones" and "anticyclones" have certain attributes in common; at the centre of each, calms prevail, while around their centres the wind blows in a rotatory direction. In all other respects they differ. The winds certainly circulate round both, but flow in exactly opposite directions in the two cases. With the anticyclones comes generally bright, and always dry, weather; with the cyclones, rain, snow, squalls, and overcast skies. The former are stationary or slow in their movements; the latter quicker and more uncertain.

"Anticyclones" are areas of high pressure, from whose centre barometrical readings decrease in all directions. It is not at all necessary that the barometer should attain any particular height in them, but only that it should be high *in relation* to the surrounding readings. They may also be of any size or shape, and may enter or leave any given region at any point. Practically, however, it is found that at different times of the year they affect particular situations more than others, so that, though numerous instances could be quoted in which well-marked anticyclones have travelled slowly across our islands, it is more usual to find the area of highest pressure firmly established over France

and the Peninsula during a large portion of the year, while at other times, more particularly in the spring, it remains as steadily fixed in the North. Round an anticyclone the wind circulates in the same direction as the motion of a clock's hands, *i.e.*, the wind blows—

From E.	on its	Southern	side.
,, S.	,,	Western	,,
,, W.	,,	Northern	,,
,, N.	,,	Eastern	,,

In addition to this rotatory motion, the wind has a direction out from the centre, a circumstance explained by the hypothesis that the area of high pressure is formed by a descending current of air which must flow outward. Round an anticyclone readings decrease very slowly; the winds in its neighbourhood are very light in force, while the weather is dry, fair, and often foggy. The hottest weather in summer, and the coldest in winter, is experienced when the dominant system is anticyclonic, and very great diurnal, mensual, and annual ranges of temperature occur when the place of observation enjoys an extraordinary or normal excess of atmospheric pressure.

"Cyclones," or areas of low pressure, are very much more active factors in the weather of the British Isles than anticyclones, our geographical position being right across the track traversed by the numerous cyclones which pass from the North Atlantic over North-western Europe. Cyclones are of very varying intensity and size, and are more or less rapid in their movements. so that their courses and effects are somewhat difficult to determine beforehand. However, the direction of the winds, which will surround the central area. is well known, and is exactly the converse of those explained with the anticyclone, viz.—

From W.	on its	Southern	side.
,, N.	,,	Western	,,
,, E.	,,	Northern	,,
,, S.	,,	Eastern	,,

It is not pretended here that the air which forms the western wind on its southern side ever completes the circulation round the central area, so as to become the easterly wind in the north, for at the same time the wind has a very decided direction inward towards the centre of low pressure, proving that there is an ascending current, with a consequent indraught all round.

As the character of weather at any place depends almost entirely on the winds experienced, it follows that the laws which govern its direction and force are most important factors in any attempt to foretell the approach of changes, or the continuation of existing conditions. To do this it is necessary, first of all, to entirely clear our minds of the old idea that the reading of a barometer at a single station, taken without any relation to other barometers in its neighbourhood, gives any sort of clue as to the probable weather about to be experienced. The lettering on a barometer is almost pure nonsense and would never by any chance be used in issuing forecasts. To show how utterly at variance the reading of the scale and the actual weather often are, two cases may be quoted. In the first a severe storm was experienced at Liverpool on January 24th, 1876, the wind between two and three a.m. having a velocity of 62 miles per hour, while the barometer read 30·10 inches, or nearly "set fair." In the other case the barometer at 6 p.m. on March 6th, 1876, read 27·94 inches, which is far below "stormy" on the barometer scale, while, as a matter of fact, a gentle north-westerly breeze only was blowing. We thus see a strong gale with a barometer at "set fair" and a light breeze when it is at "stormy." This is explained only by the fact, that given conditions of weather do not depend on a high barometer, or a low barometer, but on the relations which exist between the areas of high pressure and those of low pressure, between the cyclones and anticyclones.* In order to show this relationship, without having to quote the respective heights of the barometer at any two stations with their distance apart, a system of gradients has been introduced, by which the relative distribution of pressure can be shown over a given space without a barometer reading being mentioned. It has been said that the variation of pressure over a short distance is, as a rule, very regular, but should the distance be much prolonged, it is probable that the differences between stations at the same distance apart, but in different sections of the course of the gradient, *may* vary considerably. Areas of low pressure are somewhat similar to amphitheatres, the barometer readings rising like steps on all sides of a small central plain (Fig. 1). These steps may be at uniform distances apart, all the way up, or they may be very near each other in some places, and far apart in others, and yet the gradient for the whole distance be the same in both cases.

The wind will, however, be very different under the two conditions; breezes of uniform strength would prevail with the regular gradient, while in the other instance, light airs would be experienced

* "Science for All," Vol. II., pp. 18, 19.

in some parts of the course, and gales or strong winds in others. Air, like other elastic fluids, seeks to regain, as soon as it has been by any means disturbed, a condition of equilibrium, so that the greater the amount of disturbance, the more rapid is the rush of wind to fill up the difference; in other words, the steeper the gradient the stronger the wind.

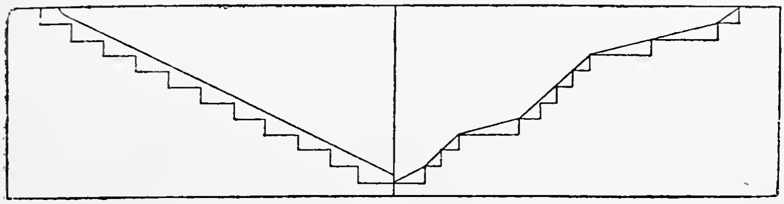


Fig. 1.—Illustrating Area of Low Pressure.

Having now explained the rules by which both the direction and force of the wind are governed, and it being a fact patent to every one that it is on the wind that our different classes of weather depend, it is necessary to revert to the cyclones and anticyclones, and show how they act, and react, one against the other.

Anticyclones are, roughly speaking, fine weather systems; they are accompanied by cold weather in winter, and hot in summer by light airs, and great "absolute" dryness, so that though fog is often prevalent, rain is exceedingly rare. The rarest, but still by no means uncommon form of anticyclone, is shown in Fig. 2, where the isobar 30·4 inches encloses a space including the south of the British Isles, the Channel, and north of France; the district where the very highest readings are found being probably somewhere in the neighbourhood of the Bristol Channel. To the south of this point, it will be seen that easterly breezes prevail; while at Valentia there is a southerly breeze; in the north a westerly breeze, over North Germany a northerly breeze, and in North France a north-easterly breeze, showing distinctly the circulation *with* the clock hands referred to before. With such a system very fine weather would prevail in the summer, the nights would be cool with slight frost on the ground, but the days clear and cloudless; while in the winter-time fog and mist would be reported, and very sharp, dry frost would prevail. It was such a system that we had over us during the first week of the May of 1879, when the only seasonable weather of that extraordinary spring was experienced. In London, unfortunately, we lay on the southern side of the anticyclone, so that the easterly breeze was felt all the time, but in Scotland, where the westerly breeze prevailed, temperature was higher, and the weather more genial. A more common form of anticyclonic system is that shown in Fig. 3, where the isobar, 30·1 inches, lies over the Bay of Biscay, and west and north of France, while low pressures are reported from the north of Scotland. In this case the easterly breeze to the southward of the area is not shown. The westerly current is shown over the whole of these islands, but splitting up into two sections after passing our shores; in the east of France, it retains its anticyclonic character, and draws into north accordingly; but in Denmark and Norway it becomes slowly and gradually cyclonic, drawing into south at Skudesnaes, and

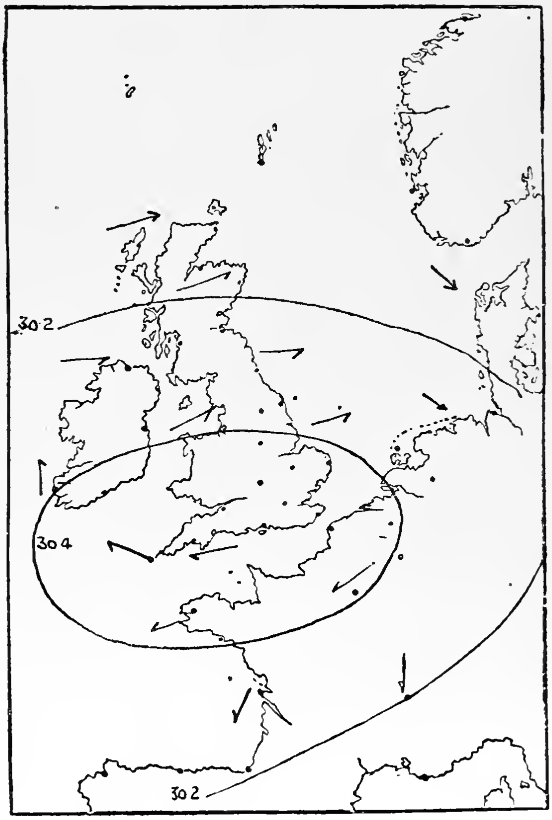


Fig. 2.—Anticyclone.

into east at Christiansund. In Fig. 4 is shown a complete reversal of the conditions in Fig. 3. Here the highest pressures, 30·4 in., are shown over the north of Scandinavia, while readings slowly

decrease southward, and are lowest over the Peninsula. There is consequently in this instance no westerly wind, a general easterly current prevailing over the whole of Western Europe; but judging

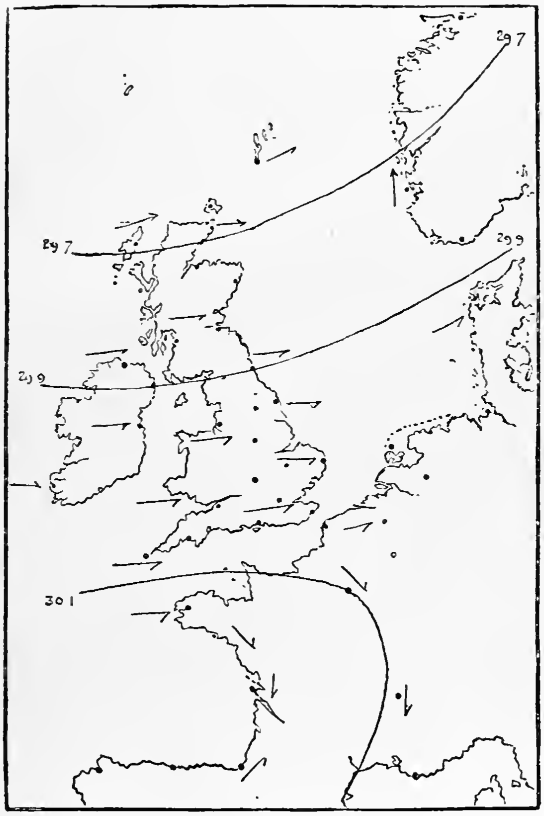


Fig. 3.—Anticyclone in S.

from the experience gained when the different atmospheric phenomena are well within the bounds of our telegraphic area, it may safely be asserted that over the Atlantic to the north-westward of the British Isles the wind draws into south-east, being part of the circulation round the anticyclone in the north, and that over the Atlantic off the Spanish coast north-easterly breezes must prevail, being part of the cyclonic circulation round the low pressure in the south. Other cases could be quoted where the anticyclone lay over Denmark and North Germany with southerly breezes all over Western Europe, or off our western coasts, bringing northerly breezes to all stations, but the main features are the same in every instance, and a general idea of the weather and winds of all areas of high pressure may be gathered from an attentive study of one example.

Cyclonic systems may be described as bad weather systems. To nearly the whole region which they cover they bring much moisture and a large amount of cloud and rain, though on their western sides, that is, where the north-westerly wind prevails, the sky is generally moderately clear, though the weather is showery. Cyclones, on account of the dampness of the air within them, occasion warm weather in winter, and cool, wet weather in summer. These systems travel, as a general rule, very much more quickly than anticyclones, the velocity of the centres which advanced over these islands on November 10th, 1875, and March 12th, 1876, nearly reaching the extraordinary speed of seventy miles an hour, but it is desirable to explain that the rate of motion of the storm centre has very little to do with the strength of the winds which surround it; they, as has been before mentioned, depending entirely on the steepness of the gradients. In Fig. 5

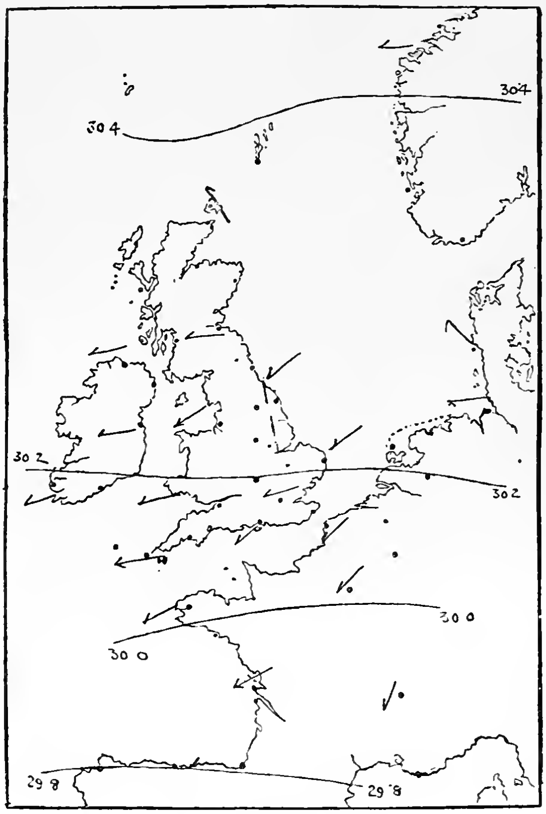


Fig. 4.—Anticyclone in N.

is shown a very good example of a winter cyclone; the small central area of lowest pressure lies over Wales, while from that point the barometer gradually rises till it reaches 30·0 in. over North Spain, and 29·6 in. in Norway. The circulation

of the wind (*against the clock hands*) is exceedingly plainly shown, while the effect of the crowding together of the isobars in increasing its strength is very visible. The lines are closest together on its

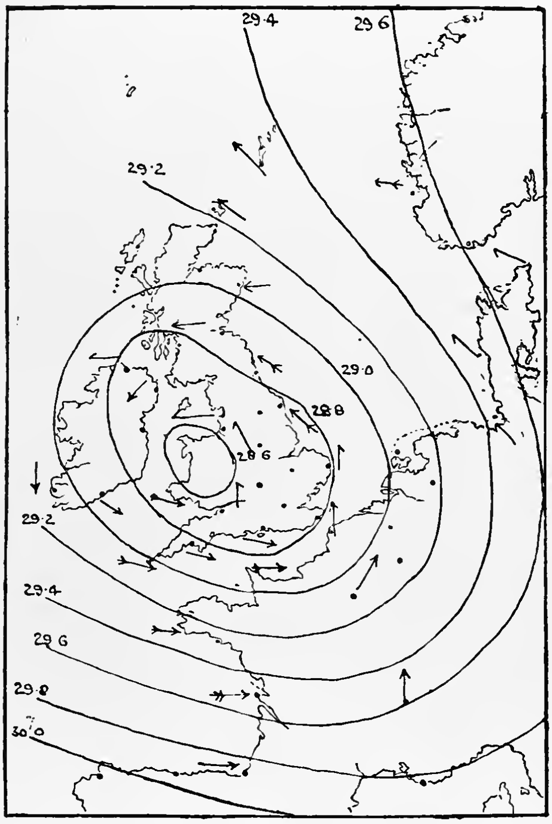


Fig. 5.—Winter Cyclone.

southern side, and gales (denoted by the feathers on the wind-arrows) are reported from the Bristol Channel, the English Channel, and the Bay of Biscay; they are close together, though less so than in the south, on its north-eastern side, and gales are reported from Scarboro' and Shields, while elsewhere, gradients being slighter, the wind, though strong, does not reach the force of a gale. As regards the weather which surrounded this centre, the reports from the various stations showed that the sky was overcast, or very nearly so, in all parts of our islands and the adjacent countries, while heavy rain had occurred in all parts of the kingdom. It must be mentioned, however, that though this example is an exceedingly good one, and that during the winter half of the year very similar storms frequently pass over these islands, yet all cyclones are not like the one figured; many are so small as to be scarcely traceable, and affect the weather only over a very small and limited area, bringing a shower or two, or a slight thunderstorm to a few stations.

As a general rule cyclones pass over these islands from west to east, and appear to be most frequently generated over the Atlantic, though it has not yet been conclusively proved that a particular depression may not, after affecting the American coasts, pass right over the ocean and appear on the shores of the British Isles. It is, at least, certain that the majority of our storms arrive from the Atlantic, and it is mainly on this account that weather forecasting in these islands becomes such a hazardous matter. As soon, however, as the motion of storms is discussed, it is necessary, instead of treating of the two systems, the cyclones and anticyclones, separately, to combine the two and to notice the constant relation which exists between them. Anticyclones appear to have a certain governing power over the direction of the motion of cyclones, the general course of storm centres apparently coinciding with the direction of the winds around the dominant area of high pressure, so that given conditions similar to those in Fig. 3, it would be safe to predict that depressions would pass from west to east—*i.e.*, from the Atlantic over Western Europe. With such a distribution of pressure in summer the cyclones would probably be of small importance, and light western breezes would prevail, with occasional showers in the west, while if the season were winter, cyclones similar to that shown in Fig. 5, bringing heavy rains and gales, might be expected. Supposing such conditions existing, and that a serious depression were coming on, the first indication would be the appearance of cirrus clouds in the extreme west; the wind in the west of Ireland would then back from the anticyclonic westerly wind to the cyclonic southerly or south-south-easterly wind; the sky would become overcast, temperature would rise, and rain would commence.

As the centre came nearer, the wind would increase in force, but as soon as the actual area of lowest pressure was over the station, calms would prevail, to be followed by a sudden north-westerly squall (as the western side of the centre passed over), a heavy shower of rain or snow, and an exceedingly quick fall of temperature. These changes would take place at each station over which the centre of the storm passed, while they would be experienced in a more modified degree throughout the whole of the area over which the influence of the storm was felt. It is worthy of remark that the clearing of the sky after the passage of a depression is much

more complete when that depression is quickly followed by a second, than when the weather is about to permanently improve ; in fact, an exceedingly clear, bright night after a stormy day is, in winter, the reverse of a favourable prognostic of fine weather for the morrow.

Supposing that the distribution of pressure were similar to that given in Fig. 4, then by the same rule depressions should appear over North Germany, and travelling westward pass across France to the Atlantic, but as a matter of fact it is exceedingly seldom that such a change takes place. The wind in the south-east may back to north or north-east, the barometer may fall decidedly, gradients increase, and easterly gales be experienced, but a well-defined area of low pressure travelling from Central Europe across France has seldom been traced, a circumstance which supports the argument that most serious storms are generated over large tracts of water. When the anticyclone is shown in the west, the depressions pass from north to south, or nearly so ; when in the east from south to north, showing that the general course of depressions is the same, or nearly the same, as the direction of the wind round the anticyclone, so that in order to know the probable point of appearance of the baric falls, it is primarily necessary to be sure of the position of the governing area of high pressure. It is to this fact that the following rough rule owes its origin. It has been asserted by distinguished meteorologists, that in nine cases out of ten it is safe to say that if it has rained to-day it will rain to-morrow, and *vice versâ*. This *dictum* is warranted by the fact previously quoted, that anticyclones when once formed have a great tendency to remain stationary, or nearly stationary, over the place of their origin, so that it follows, as cyclones are continually passing round the margins of these areas of high pressure, a station which is within their influence, and has experienced the rain and cloud of one, will in the natural order of events experience a recurrence of these visitations with each succeeding depression, thus having the same character of weather for a shorter or longer period according to the time of duration of the anticyclone. A striking example of the truth of this rule was given in the long and severe winter of 1878–9. Time after time it was hoped that the area of high pressure in the north had been dissipated, and the consequent easterly winds had disappeared, yet the anticyclone reappeared over Northern Europe, and north-easterly winds returned with frost and snow.

Situated as are the British Isles, an immense amount of judgment and experience is required to accurately foretell the weather. It has been pointed out how the two governing systems—the cyclone and the anticyclone—affect our weather, and also how the cyclones travel when once the anticyclone has been formed ; but to be able to tell how long an anticyclone will last when formed, how serious or slight, how rapid or slow a cyclone may ultimately prove to be, which is only just impinging on our coasts, has up to the present time proved an insoluble problem to meteorologists. It is more than probable that even after great advances have been made in the science of meteorology, diurnal forecasting will continue, at least for Western Europe, to present the same interesting cases of failure which at present distinguish it ; but, on the other hand, seasonal forecasting might at any moment step into almost absolute certainty. The reports of the weather experienced in various parts of the world during the year 1879 furnished many instructive features. All over Western Europe the winter and spring were characterised by very great severity, right down into Southern Europe, snow-storms and frost prevailed until the year was well advanced, while the sea on the shores of the Levant was at one time coated with ice for some miles from the land. In China, also, easterly gales of exceptional severity have prevailed with ice and snow in many parts of the country. This general inclemency, it is almost certain, must be accounted for by cosmical or other phenomena outside the earth's surface, and such phenomena having probably regular periodic changes, the elucidation of the problem might at any moment be reached. With diurnal forecasting, on the contrary, where the weather of the day depends on the course and intensity of an approaching and imperfectly-known factor, very great uncertainty must always exist. The accident of the application of electricity to signalling purposes, combined with great experience in past weather changes, has indeed enabled us *often* to form a correct estimate of the probable weather by the atmospheric changes which are already in progress ; but it is more than likely that meteorologists will sooner be able to say with certainty that such and such a future season will be wet or dry, warm or cold, than that such and such a future day will be fine or unsettled.

LODGERS AND BOARDERS IN LOWER LIFE.

By Andrew Wilson, Ph.D., F.R.S.E., etc.

THE character of the "parasite" is one which from classic times has been deservedly held up to ridicule and scorn by the universal consent of humanity. The cringing, dependent, and fawning servitor, dancing attendance upon the heels of usually a tyrannical patron, constitutes a picture in favour of which no one may feel prepossessed; and the general idea of such a relationship is that of a contemptible alliance betwixt master and servitor, calculated to effect no good work upon their human surroundings. The term "parasite," as applied in lower life, whilst it possesses certain analogies with the human state so called, nevertheless exhibits a widely different aspect when its entire features are taken into consideration. The animal parasite, in the majority of cases, is unquestionably, like its human representative, a degraded creature. It will be found most frequently to have lost whatever independence it once possessed, and to have merged its existence in a slavish dependence on its host. In not a few cases, this dependence will be found to have proceeded so far, that the parasite has become stomach-less and mouthless, and feeds itself, as best it may, on the fluids which its host elaborates for personal use. Thorough degradation may thus be said to follow the adoption of a parasitic life in cases where such an existence is best typified in the animal world. But here the comparison of the human and animal dependent may be lawfully said to end; and at this stage the differences begin, on the other hand, to be plainly apparent. The parasite in higher life is at the beck and call of his master, and is bound to respond to every whim and caprice of his owner. Not so the parasite in lower life, which exists usually as a source of irritation, and often as a cause of disease to its uninviting, and it may be unconscious, host. The human dependent may, it is true, exist for his own ends, and may ultimately benefit himself through his despicable ways and through the petty meannesses of his life. But such advantage may be said to be the invariable rule of the parasite in lower life. The latter not only lodges, but boards at the expense of its host. It obtains lodgment and food in the easiest fashion and in the cheapest manner. It is a persistent "bad lodger" which not only pays no rent, but may, in the course of its existence, benefit itself by the physical ruin of its benefactor. Sindbad's "old man of the sea" was not a more persistent tenant on that hero's shoulders, than are most parasites on or within the bodies of their hosts. And, unfortunately, the latter may hardly be shaken off as was Sindbad's ancient burden; inasmuch as, when parasitism has become the way of life of a living organism, the law that "habit" becomes "a second nature" receives a new illustration, and the parasitic existence, once begun, tends to become the perpetual and normal life of the dependent being.

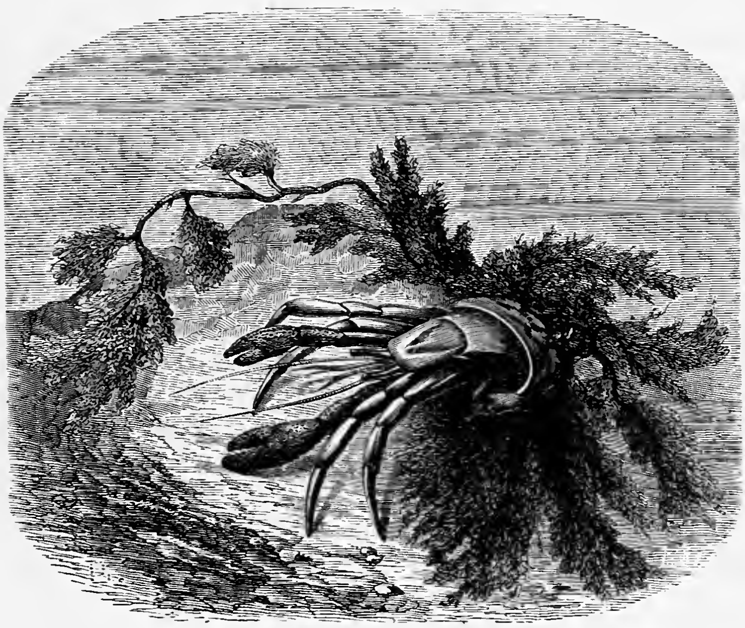


Fig. 1—Hermit-Crab.

Thus much by way of comparison of a way of human existence with a curious pathway of animal life. Let us endeavour, in the next place, to gain some ideas of the structure and development of certain typical parasites, and thereafter seek briefly to discuss the probable origin and laws of parasitic life at large. In such a zoological ramble we may light upon facts which may not only "feed the curious"

within us, but serve the higher mission of intellectual nurture, in providing food for thought and wise reflection.

Some simple cases of parasitism may first engage our attention, since these less complicated relations betwixt animals may serve perchance to show how the more complex associations have been acquired. Many cases are known to naturalists in which one animal attaches itself to, or merely associates itself with, another animal of widely different kind. Such association is not only of constant and invariable occurrence, but is moreover inexplicable, save perhaps on the idea of a chance companionship, which, under the influence of habit, has become a sworn friendship. No better example of such association could be found than that of a certain species of sea-anemone (*Adamsia palliata*) which attaches itself to the shells in which hermit-crabs (*Pagurus Prideauxii*) ensconce themselves after the manner of their kind (Figs. 1, 2, 3). Invariably we find crab and anemone dwelling together; the former toiling along, house on his back, and his anemone-friend, securely posed on the house in turn, is carried about much as the accompanying illustration (Fig. 2) depicts a colony of tube-worms borne on the shell in which the crab resides. Between these "messmates," as they may be termed, the best of understandings appears to exist. Constant association, perpetuated from generation to generation, has perfected relations of a friendly character between crab and anemone. The crab has been seen to feed the anemone by aid of his long nippers, and to remove the anemone to a new and larger shell when, through his physical increase, a change of quarters was demanded. Here there is association, which, if it may hardly be termed beneficial in so far as the crab is concerned, nevertheless presents us with an instance where the parasite or anemone has contracted a persistent habit of attachment. Such a habit, pursued in other cases, may lead, as we shall see, to the beginning of true parasitism.

Of a more intimate kind, and more nearly approaching parasitism itself, is the relationship known to exist between such animals as sea-anemones and certain fishes, and between such molluscs as mussels and certain small crustaceans named "pea-crabs." Any visitor to the seaside who has touched the outspread tentacles of a sea-anemone, knows full well how quickly the animal retracts the feelers, and contracts its entire frame. The object of such sensitiveness is not far to seek. Since the prey of the anemone—consisting of crabs, whelks, and all unwary creatures which may stumble across its tentacles—is captured by the tentacles, and, primarily, through the warning which the property of sensation gives to the feelers of the animal, it would be therefore a perfectly just assertion to say that a sea-anemone is a highly sensitive animal, and that objects touching its

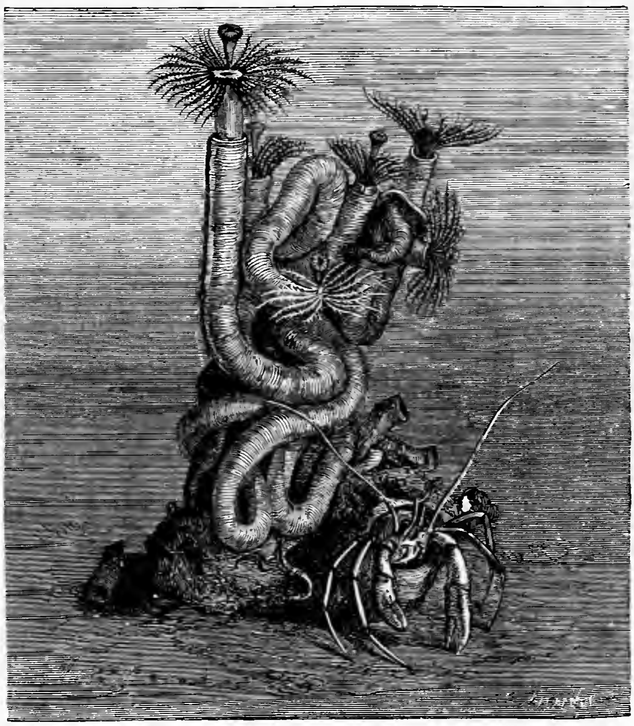


Fig. 2.—Hermit-Crab and Tube-Worms.

tentacles are readily and quickly seized and engulphed within its sac-like body. But what may be said of the relationship between certain tropical sea-anemones of large size, and some small fishes, whose habitual dwelling-place appears to be the interior of the anemones' bodies, and which swim in and out of the mouths of their hosts at will? Nor is the case any the less surprising when we find it asserted on good authority that the anemone may contract its body, enclosing the fish, and thereafter expanding itself, allow its "messmate" to swim freely about, only to return again, however, to its strange but habitual dwelling-place. Considering the rapacity of ordinary

anemone-character, as illustrated by the seizure of food, how may the immunity of a fish which has ventured not merely into the lion's jaws, but into its very stomach, be accounted for? Once again we are forced to fall back upon the idea of "habit, use, and wont," as inducing such an harmonious relationship. It might be suggested that the fish may benefit from the easy terms on which it may obtain food within the stomach-sac of the anemone. If this view be correct, then the case may truly be described as that of two "mess-mates;" but the details appear as strange and curious after this suggestion as before. Such a case may show how parasitic habits might be inaugurated in the case of an animal more likely to become wholly dependent on a host than the fish, since the partial dependence of a likely animal on the anemone might be replaced by a fuller and more complete life of ease and indulgence.

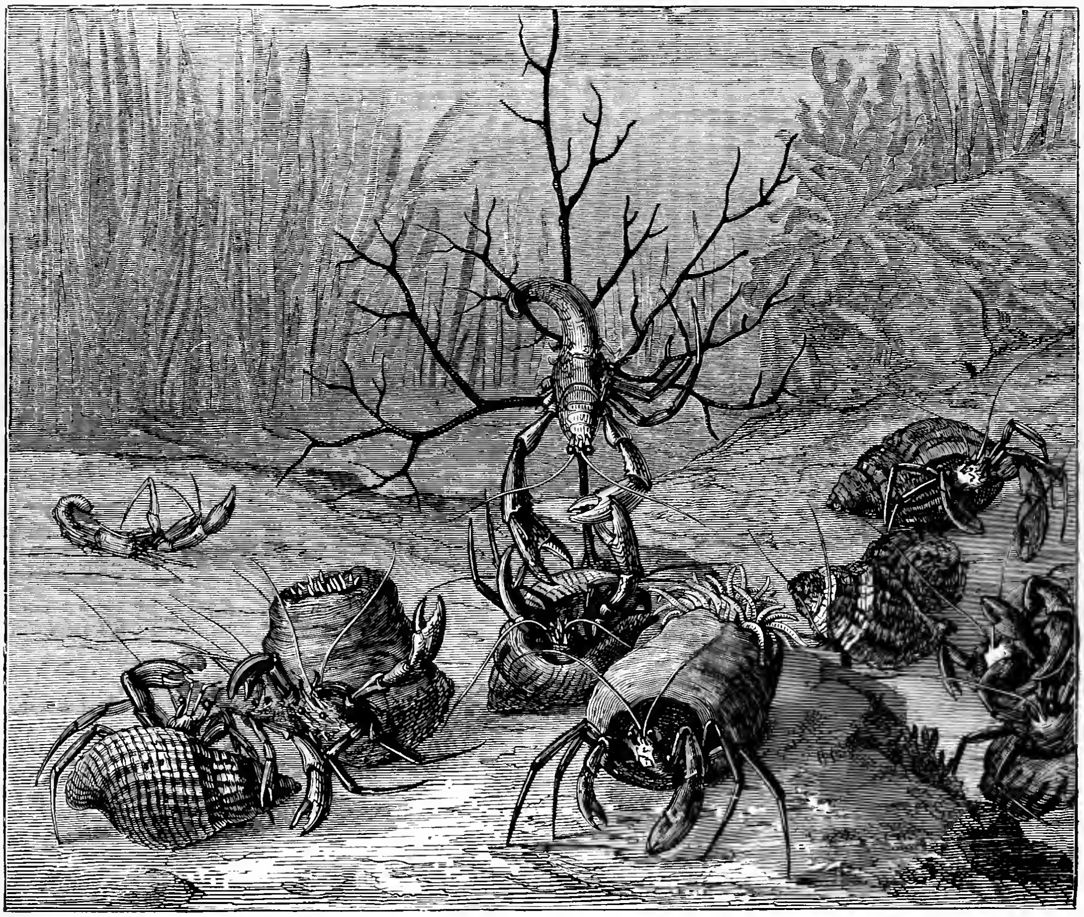


Fig. 3.—Hermit-Crabs Fighting.

Somewhat resembling the preceding case is that of the "pea-crabs" (Fig. 4), those minute crustaceans which occur not merely within the shells and bodies of mussels, but are also found as lodgers within the breathing-chambers of the "sea-squirts" or Ascidians (Figs. 5 and 6). How or why these crustacean intruders are tolerated amongst the sensitive tissues of their hosts, is another mystery, inexplicable as to its origin, and equally mysterious in its continuance, save on the supposition that custom has habituated the mollusc or sea-squirt to the presence of its guests. Pliny of old, indeed, credited the pea-crab with the function of pinching its landlord by way of warning him against the inroads of other and perchance less welcome intruders; but the suggestion does more credit to the classic naturalist's ingenuity than to his knowledge of animal psychology and relationships. That the pea-crabs are most probably "lodgers" only,

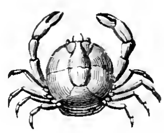


Fig. 4.—Pea-crab.

and not boarders, within the sea-squirts at least, seems a likely idea, from the writer's own observation of the habits of these crustaceans. Pea-crabs may be seen to emerge at night from sea-squirts

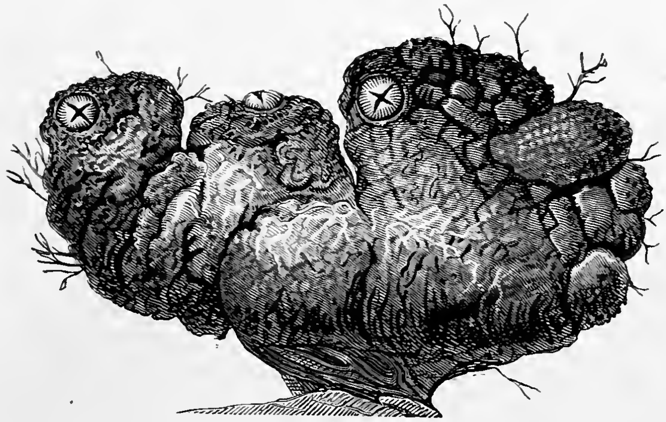


Fig. 5.—Simple Ascidian (*A. microcosmus*).

kept in an aquarium, to feed on the floor of the vessel or tank; the crabs retreating to their shelter, on being alarmed, with a rapidity which speaks volumes at once for their familiarity with their place of refuge and for sea-squirt tolerance with lively lodgers.

In these cases, a habit of association has clearly been contracted, with the result of invariably inducing the stated companionship of two animal forms, widely separated from each other in point of structure and rank in the zoological category. We may now proceed to note the details of some cases in which this association has developed into a still closer intimacy, and in which the limits and territory of true parasitism may be said to be attained.

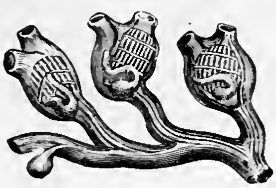


Fig. 6.—Social Ascidian (*A. pedunculata*).

Amongst the parasites that infest the human territory, and that of higher animals at large, the tapeworms are perhaps the best-known examples. These organisms inhabit, as their special sphere, the intestines of man and other warm-blooded animals —namely, quadrupeds and birds. They may attain a length of many feet; and when scientifically examined, each tapeworm is seen to consist of, firstly, a very minute "head," armed with hooklets and suckers for adhesion to the intestine; secondly, of a slender portion composed of imperfectly-formed joints, the so-called "neck;" and, thirdly, of numerous flattened "joints," of oblong shape. It must be first noticed that the "joints" do not correspond to the joints or segments of an ordinary worm. In the tapeworm, indeed, each joint is really a semi-independent animal; and the whole worm, instead of being a single organism, is thus in reality a collection or colony of beings. The "head" is the most personal part, so to speak, of this compound organism, since the joints are produced from the head and neck by a veritable process of "budding." Each fresh joint appears to be produced between the head and the already-formed segments. And as this process of growth may be said to proceed continuously during the lifetime of the organism, we may readily enough understand how the tapeworms may attain the length and dimensions they frequently exhibit.

The tapeworms have little to boast of in the way of structure or organisation. The head contains the main masses of the nervous system, which send two nervous filaments backwards through the joints, and two main tubes or "water-vessels" run one down each side of the body. Each "joint" may be described as simply a receptacle for the development and production of eggs. In each joint we see the greatly-branched "ovary" or egg-producing structure, within which thousands of eggs—destined, under favourable circumstances, to produce as many tapeworms—are developed. Thus we clearly appreciate the almost unlimited fertility of these animals, when we discover that the organism consists of many segments, each capable of producing its thousands of eggs; whilst each egg that undergoes full development is invested with the power of giving origin in turn to a tapeworm-organism composed, as before, of its hundreds of joints.*

What is the life-history of such an organism? is a query which may best be answered through a study of its development. Liberated from the body of their host, the joints of the tapeworm, through their decay, disperse their minute eggs abroad. The eggs, to undergo development into tapeworms, require, however, to pass the first part of their existence in a different animal from that in which they are to reside as mature tapeworms; that is to say, the egg of the common tapeworm (*Tænia solium*),

* See Figs. 3, 4, 5, pp. 371, 372, "Science for All," Vol. I.

which inhabits the human digestive system, would come to nothing were it to be swallowed by man. For its due development, it requires to be first swallowed by a warm-blooded animal, as a first host—the animal in question being a pig. Swallowed by the pig, the egg of the tapeworm soon liberates from its covering a little "embryo" provided with six hooklets. This young tapeworm shows no disposition to develop the characteristic form of its parent within the pig, but at once proceeds to bore its way through the walls of the animal's stomach, and to take up its abode usually in the pig's muscles, or it may be in the liver, brain, or some other organ. Here it becomes a "resting-larva." It develops around its body a sac or bag containing fluid, and is now known as the "scolex." Already we may perceive a minute head and neck, but no further traces of the mature tapeworm are to be seen. Here, also, it can attain to no further development. Its career within its pig-host ends thus; and if the pig should die a natural death, and be buried, the "resting-young" of the tapeworm would share the fate of disintegration, destruction, and decay, which would, in the latter event, await the tissues of the pig. Let us imagine, however, that, instead of the unlooked-for and unusual contingency above noted, the pig's muscles are in due season converted into pork, and that man partakes of that commodity, especially in an uncooked or imperfectly prepared condition. Then, each "resting-tapeworm" within its sac, and derived from the muscles of the pig, receives a fresh start in life, and enters upon the concluding phases of development. For, when swallowed by man, the little sac is dissolved. By means of its hooklets, the resting-larva attaches itself to the lining membrane of the digestive system. Next ensues a process of budding. Joint after joint is duly produced; and the form of the mature tapeworm, with its eggs ready for development, as we at first beheld it, again appears in the round or cycle of development.

Such is the curious story of the development of these parasites. The main features of that biography consist in the remembrance of the facts that these animals possess two hosts, and that they do not attain full development in the animal which first harbours them. Thus, from the resting-larvæ of underdone or "measly" pork, man derives the common tapeworm. From underdone beef he may obtain another kind of tapeworm, the first stages of whose existence are thus spent within the economy of the ox. The young of the tapeworm commonly found in the dog and fox inhabit the liver of the rabbit; another parasite of the dog being obtained from the brain of the sheep. The cat obtains its parasite in the most natural fashion from the liver of the mouse or rat. And man, in turn, may act as a first host when he harbours in his liver the dreaded "hydatids," which are simply the immature young, or resting forms, of a tapeworm attaining maturity in the dog. No more curious life-history than that of a species of tapeworm (*Tænia cucumerina*) can well be imagined; this parasite inhabiting the dog's digestive system. The resting-young of this tapeworm inhabit the body of the dog-louse—which is duly swallowed by the dog in the act of cleaning his coat—and there becomes the full-grown tapeworm. The eggs of this mature parasite are in turn swallowed by the dog-lice, and become the resting-young which are destined to repeat the history through which their progenitors have passed. Here there is seen parasitism within parasitism; and, to say the least, it would be a puzzling task to account for the origin of the somewhat complex relationship which has thus been developed betwixt the louse, the tapeworm, and the canine host, which protects the one and gives shelter to the other.

Equally interesting, and in some respects similar to the development of the tapeworms, is the history of the flukes (Fig. 7, A). Every one has heard of these flat-bodied "worms"—each comparable to a single joint of a tapeworm—which inhabit the bile-ducts and liver-tubes of the sheep, and produce those symptoms of emaciation and disease in that animal, collectively known as the "rot." The eggs of the fluke escape into water, and give birth to young, or embryos (Fig. 7, B), which at first swim freely about. Soon the young fluke loses its locomotive powers, becomes a tadpole-like being, and enters the body of a fresh-water snail. There it remains quiescent, but undergoes changes which bring it nearer the condition of fluke. When the snail is swallowed by the sheep in the act of drinking—or it may be when the young flukes escape from the snail into water and thus gain ready access to the sheep's economy—the final stage in development is duly brought about; and the young flukes, making their way to the liver of the animal, become perfect and mature beings. Thus we see that, as in the tapeworms, so in the flukes, two hosts are required for the due development of these parasites; and it may not be amiss to remark in passing upon the fortunate nature—in so far as the higher animals or final "hosts" are concerned—of this arrangement. But for the thousand and one chances of destruction

which await the eggs of these parasites, and for the chances which tell against their successful lodgment in their first hosts, and also against their successfully overcoming the difficulties of their complicated development, man's estate would be simply overrun

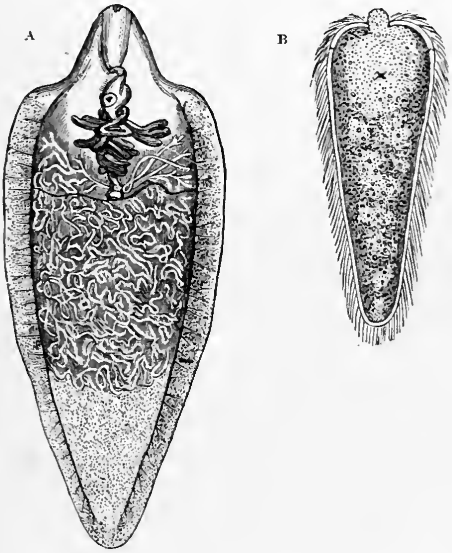


Fig. 7.—Development of Liver Fluke.
A, Sexually mature (after Blanchard). B, Embryo (after Leuckart).

with these organisms, and higher animal life at large might well fear rapid extermination.

Instructive and interesting also is the account of the development of the notorious *Trichina*,* which is capable of causing grave symptoms or death by its attack. This parasite is a minute thread-like worm, which, as it exists in the *muscles* of man, of the pig, or other animals, is immature and harmless. When the flesh of the pig, for example, containing these trichinæ—which lie coiled up each within a little "cyst" or bag—is eaten by man, a wondrous activity is exchanged for their previously inert condition. These parasites, set free within the human stomach, rapidly produce their young by thousands. These young are debarred by the laws of their development from attaining any further advance in life before passing a term of pupilage, so to speak, in the muscles. Hence arises the danger of trichina-visitation; and then comes the tug of war. For the rising generation of these parasites, produced in the stomach, now bore their way through the tissues to a resting-place in the muscles, and in the act of migrating cause pains and illness often of a serious character. Once settled down in the muscles, all danger, however, is past. For each worm develops around itself a sac or bag, wherein it lies ensconced until swallowed by another warm-blooded animal—an utterly unlikely fate in the case of man's muscles, the parasites of which will simply undergo degeneration, and be ultimately converted into so many specks of lime.

* See Fig. 6, p. 372, "Science for All," Vol. I.

What are the lessons which a subject, that at first sight might be deemed of unsavoury kind, seems well calculated to teach us concerning parasitism and its origin? Briefly summed up, we may say that, firstly, parasitic habits are certainly not of original nature, but have been acquired—in other words, the parasite was not always attached and helpless, but was once free and dissociated, and acquired its dependent habits in consequence of some alteration in its way of life which benefited its race. How may such a statement be supported? is a natural enough inquiry. I reply, by the consideration of the various graduated stages and modifications in parasitism, and by the life-history of parasites at large. We may trace every stage in the parasitic dependence, and in the degree of intimacy which exists betwixt hosts and lodgers. From the simple condition of mere lodgment and attachment (as in the case of the anemone and hermit-crab), to that of "messmates," or pure "lodgers," is an easy transition. The fishes living within the anemones, and the pea-crabs within mussels and sea-squirts, exemplify cases of the latter description. In these instances, there is an association more intimate than that existing between the anemone and crab; and although there is an independence of host and lodger, there are to be traced, nevertheless, the beginnings of truly parasitic habits. The tapeworms and their allies, as true parasites, illustrate beings which have undergone great modification of their parts and organs, and which, having gradually accommodated themselves to their surroundings, have become lodgers and boarders, feeding themselves at the expense of their hosts.

But we gain still clearer ideas of the originally free and non-parasitic state of animal lodgers and boarders, if we consider the meaning of the free stages witnessed in their development. No better illustration in support of this latter idea, that their development affords a clue to the whole history of parasites, could be cited than that of *Sacculina* (Fig. 8, B)—a low form of crustacean, and a kind of poor relation of crabs, shrimps, and their allies. The sacculina exists as a bag-like growth on the bodies of hermit-crabs. It may be described as a bag of eggs and nothing more, attaching itself by root-like

processes to its host, from whose tissues it absorbs its nourishment. From its structure as an adult sacculina, indeed, we could not guess its true nature, seeing that it possesses few or none of the ordinary belongings of the animal creation. But if we watch

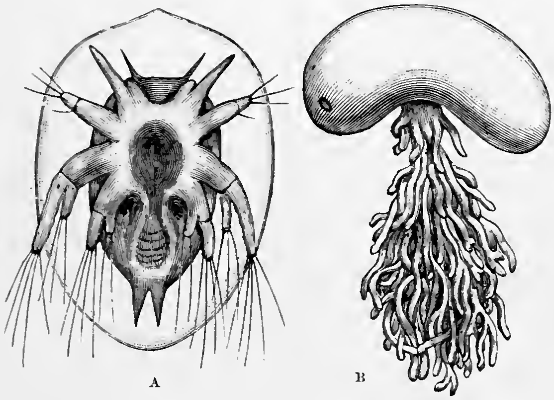


Fig. 8.—Development of *Sacculina* (after Haeckel). A, Larva; B, Mature Animal.

the development of one of the many eggs this bag-like being contains, we may then hazard a guess as to its nature and concerning the history of its past. Each sacculina-egg gives birth to an active little creature, named a *Nauplius* (Fig. 8, A). This little being possesses three pairs of legs or feet, an oval body, and a single or cyclopean eye. Soon the body becomes enclosed in a "shell;" the front pair of limbs increases at the expense of the others, which are cast off; whilst six pairs of swimming-feet are developed in their place. Ultimately, these little creatures attach themselves to their crab-hosts; the limbs drop off; the two front limbs remain developed, and become altered to form organs of adhesion to their hosts; and the body itself finally assumes the form of the sausage-shaped organism we see in the adult sacculina (Fig. 8, B).

Thus, if "development" may be trusted as a criterion of the history of the sacculina race, we may believe that at first these parasites were represented by free-swimming beings resembling the "Nauplius" (Fig. 8, A), which now appears at the first stage in their lives. And it may with equal justice be assumed, from the facts which nature reveals to us, that the fixed and rooted Sacculina is itself a later product of development, and appears as the result of altered habits and of a changed way of life on the part of the original race. Such conclusions, though merely hypothetical, are not unsupported by the history of other animal forms. On the contrary, change and variation may be regarded as representing factors and means of normal kind in inducing alterations in the structure and habits of living beings. No one may doubt the existence and operation in the world of life of laws which direct animal and plant forms along the "grooves of change." Our difficulty lies, not in determining the existence of these laws, but in reaching the "law within the law," on which the degree and succession of changes depend. Such ideas that alteration and variation are natural actions of life, are the result of that wider study of living beings which has of late years been prosecuted. Of old, the "fixity" of species and the permanency of animal and plant forms was esteemed an axiom of biology. Now, we know that the production of varieties and races is one of nature's statutory procedures, so to speak. We do not yet know, it is true, the limits of variation in different animals or plants; but experience shows us that these limits probably vary greatly in different species. The causes of variation are likewise still obscure, but amongst these causes, we may rank the influence of surroundings and of changed environments as of the highest importance. One of many theoretical conclusions to which the subject of parasites may, therefore, lead, is that alteration and modification of the lives and structure of animals appear to be a normal occurrence in nature. Under the influence of new ways of life and of changed conditions, animals once free have become attached as parasites, and, from the possession of definite structure and organisation, have become degraded, and have degenerated to the existing state of many parasitical forms. Change and modification are thus seen to be important features in ruling the destinies of living beings; and no better examples of this latter fact may be cited than those illustrating the manner in which the so-called "vicious circle" of parasite life is perpetually maintained.

INDEX.

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